AERODYNAMIC CHARACTERISTICS OF THE V-SHAPED TAIL

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Preface

Symbols Used

C_L , Lift coefficient, L/qS

C_D , Drag coefficient, D/qS

$C_{c'}$, Cross-wind force coefficient, C'/qS

$C_{l'}$, Rolling moment coefficient, L'/qSb

C_m , Pitching moment coefficient, M/qSc

$C_{n'}$, Yawing moment coefficient, N'/qSb

where L is the lift

D , drag

C', cross-wind force

L', rolling moment

M , pitching moment

N', yawing moment

q , dynamic pressure

S , wing area

c , average wing chord

b , wing span

and

α , the angle of attack

ψ , angle of yaw (positive when the right wing tip tends to move to the rear, as viewed from the pilot's seat.)

γ , dihedral angle

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Summary

This report presents the results of a series of tests conducted in the Georgia Tech 30-inch wind tunnel to determine the effect of dihedral and yaw on the aerodynamic characteristics of the V-shaped tail. A Clark Y airfoil of rectangular plan form was tested at four dihedral settings. Force tests at five angles of yaw were made for each dihedral setting. From these tests the coefficients of lift, drag, and pitching moment, and the rates of change of rolling-moment, yawing-moment, and cross-wind force coefficients with angle of yaw were determined.

The results revealed a marked delay of the stall, an increase in minimum drag, and a decrease in maximum lift, lift curve slope, and pitching-moment curve slope with an increase in the dihedral angle. Positive dihedral produced a stable rolling moment and an unstable yawing moment and cross-wind force. Negative dihedral resulted in stable yawing moment and unstable rolling moment and cross-wind force. These tests showed that the plan form of the wing is of major importance among the factors affecting airfoil characteristics of a wing with a large dihedral, and also showed that the interference effects between the model and support are of major importance in testing an airfoil with a large dihedral.

Introduction

A V-shaped tail is a horizontal tail surface set at a dihedral angle. The tail consists of two parts: a fixed surface and flaps. Flaps, when operated together, combine the functions of rudder and elevators. The effect of elevators is achieved when the flaps are lowered or raised simultaneously. When they are operated differentially, that is one flap being raised and the other lowered, the effect of rudder is obtained.

The V-shaped tail has been known for over ten years[1], but very little is known about the aerodynamic characteristics of this new arrangement of tail surfaces. Among the important aerodynamic characteristics of the V-shaped tail are: a) the slopes of the lift and pitching-moment curves, which give an indication of the amount of longitudinal stability; b) the rates of change of rolling-moment, cross-wind force and yawing-moment coefficients with yaw, which give an indication of lateral stability; and c) the amount of drag. The last is of considerable importance, since it is reasonable to believe that with less wetted area required for the new tail, the drag will be less and, consequently, the speed of an airplane will be increased.

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[1] "The Rudlicki Vee Tail", Aircraft Engineering, Vol. IV, No. 37, March 1932, pp.63-64.

The effect of dihedral on the aerodynamic characteristics of airplanes has been experimentally determined in a few instances.[2,3] However, these results apply to wings rather than to tail surfaces, and, therefore, the range of dihedral angles analyzed is limited to not more than 15 degrees. The tests reported herein include the determination of the effect of dihedral angles ranging from - 20 degrees to + 40 degrees.

The effect of yaw on the lateral-stability characteristics of airfoils has been theoretically and experimentally determined in many instances. The works of Bamber and House[4] and Sigburd Hoerner[5] were found to be most useful for this report.

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[2] J. A. Shortal, Effect of Tip Shape and Dihedral on Lateral-Stability Characteristics, U.S. National Advisory Committee for Aeronautics, Technical Report No.548, 1935.

[3] C. H. Zimmerman, Aerodynamic Characteristics of Several Airfoils of Low Aspect Ratio, U.S. National Advisory Committee for Aeronautics, Technical Note No.539, 1935.

[4] M. J. Bamber and R. D. House, Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics, U.S. National Advisory Committee for Aeronautics, Technical Note No.703, 1939.

[5] S. Hoerner, Forces and Moments on a Yawed Airfoil, U.S. National Advisory Committee for Aeronautics, Technical Memorandums No. 906, 1939.

Model and Apparatus

Only one airfoil was used for the experiments. This airfoil was constructed of laminated mahogany to the Clark Y profile. The airfoil was originally made accurate to ± 0.003 " but is slightly warped at the present time. Plan form and elevation drawings of the wing are given in Figure 6 and two photographs of the wing set at a dihedral angle of 40° in Figures 2 and 3.

The airfoil was cut at the mid-section and held together at the desired dihedral setting by metal straps and angles. A set of one strap and two angles was required for each dihedral setting.

In order to eliminate unnecessary variables and to make all results comparable, the overall dimensions of the two halves of the wing set at a given dihedral were kept the same as those of the wing with no dihedral. That is, the wetted areas of the wings were the same, but the vertical and horizontal projections of a wing with dihedral were reduced respectively by the Sine and Cosine of the dihedral angle. It was found necessary to cut some material from the center-section of the airfoil before the two halves could be set at a dihedral angle of 40 degrees. This cut was carefully filled with wax for other dihedral settings. The model was polished before each set of dihedral runs was performed.

All tests were made in the Georgia Tech 30-inch wind tunnel (Fig.1). The wind tunnel is of the open throat, closed circuit type, with single return in a vertical plane. The tunnel is completely described in Student Technical Report No. 4, 1932-33.[6]

The method of supporting the model in the jet is illustrated in Figures 4 and 5. It consists of a metal frame held in place by six wires leading to balances and a skew wire to which a counterweight is attached. All wires used were 0.012" diameter piano wires, annealed in order to produce the required flexibility.

The angle of attack of the model was changed by a rotating disc of the model support. This disc is so constructed that it may be rotated in its seat and set at intervals of about three degrees. By rotating this disc about the Z-axis, angles of yaw of the model are obtained in 10° increments.

Tests

The wing was tested at dihedral angles of - 20°, 0°, 20° and 40°. Each dihedral wing was tested at angles of yaw of - 20°, - 10°, 0°, 10° and 20°. At each angle of yaw, tests were made for angles of attack of about 4° beyond the zero lift to about 1° to 8° past the maximum lift, in approximately 3° intervals. At all angles of yaw, enough tests were made to obtain the values of minimum drag and maximum lift. For each test, all six components of force and moment were measured.

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6 G. A. Mahoff, L. B. Rumph, and W. R. Weems, Calibration of Small Wind Tunnel at Georgia Tech. Unpublished student technical report, Daniel Guggenheim School of Aeronautics, Georgia School of Technology, Report No.4, 1932-33, 15 pp.

The tests were made at a dynamic pressure of 50 Kg/M^2, which corresponds to an air speed of about 65 miles per hour under standard atmospheric conditions. The Reynolds Number of the tests was about 133,000 based on the chord of 2.88 inches.

Results

The assumptions usually made in the study of airplane stability were also made in these tests. The two most important of these assumptions are:

1. The wing span, area, and average chord used in computing the coefficients are those of the wing with no dihedral.
2. The angle of attack is the angle between the relative wind and the chord of a straight wing, or is corrected so as to be such.

The axes used in specifying the moments were wind axes that intersect on the wing model at the midspan 50 percent chord point of the basic chord.

The lift, the drag, and the pitching moments, corrected for tunnel effects, are presented in the form of standard absolute coefficients plotted against the angle of attack. Figures 7 to 10 and Figures 12 to 15 are sample plots. Figure 11 shows the effect of dihedral on lift coefficient corrected for the reduction in the projected area of the wing on a lateral plane.

The rolling moment, the cross-wind force, and the yawing moment were corrected for initial asymmetry by deducting the values obtained without yaw from the values obtained with yaw. All coefficients were plotted against the angle of attack; Figures 16 to 27 are sample results.

The stability characteristics, $\left(\frac{d C_{\ell'}}{d \psi}\right)_0$, $\left(\frac{d C_{c'}}{d \psi}\right)_0$, and $\left(\frac{d C_{n'}}{d \psi}\right)_0$, were obtained by measuring at zero yaw the slope of the curves of the coefficients against the angle of yaw. Figures 28 to 30 give the variation of the stability characteristics with the angle of attack.

The increments of rates of change of $\left(\frac{d C_{\ell'}}{d \psi}\right)_0$, $\left(\frac{d C_{c'}}{d \psi}\right)_0$, and $\left(\frac{d C_{n'}}{d \psi}\right)_0$ due to dihedral angle, for 0° and 10° angles of attack, are plotted against dihedral angle in Figure 31.

Discussion

The reader should bear in mind that the results herein discussed apply only to airfoils, and that in making stability calculations the characteristics of the airplane as a whole must be very carefully taken into account. As all tests were made at the low Reynolds Number of 133,000 , any conclusions as to the effects of the variable factors should be drawn with the above fact in mind.

A general survey of the curves demonstrates the appreciable effects which dihedral and yaw (when combined with dihedral) have on the aerodynamic characteristics of the wings.

The wing forces, in general, were very little altered by yawed flow (at zero dihedral). Thus, at angles of yaw of $\pm 10^\circ$, the lift and drag forces were practically unaffected (Fig.7). More than that, the pitching-moment was found to have remained practically unchanged up to angles of yaw of $\psi = \pm 20^\circ$. (Figure 12). Referring now to the curves in greater detail, the effects of yaw and dihedral on the aerodynamic characteristics of the model wing may be listed as follows:

Lift Coefficient

According to Betz[7], the lift coefficient, C_L, decreases approximately as $\text{Cos}^2 \psi$, where ψ is the angle of yaw. Following the Betz method, the lift was found to be the same at high angles of attack and angle of yaw of 10°, but about 4 percent higher at low angles of attack.

The coefficients being based on the area of the wings with no dihedral, the maximum lift would be expected to be lower with dihedral because of the reduction of the projected area of the wing on a lateral plane. Shortal[8] found that the reduction in maximum lift coefficients was proportional to the reduction in the projected area. However, this was not the case in our experiments. Figure 11 shows that the lift coefficients, corrected for the reduction of the projected area, were, in general, lower than those predicted by Shortal. The maximum lift coefficient of a wing set at a dihedral angle of 20°

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[7] Betz, A., "Applied Airfoil Theory" in Durand, Aerodynamic Theory, Vol. IV (Berlin: Julius Springer, 1935) pp. 1-129.

[8] Shortal, op. cit.

was approximately the same as that of a wing with no dihedral; however, the dihedral angle of 40° resulted in a 12 percent reduction of the maximum lift coefficient. This was attributed to large interference effects between the model and the disc of the model support. Close examination of Figure 2 will show that, at large dihedral angles, the size of the disc inserted between the two halves of the wing is a major factor in producing disturbed motion around the airfoil.

A survey of the curves of lift coefficient plotted against the angle of attack (Figures 7,8,9, and 10) reveals, as would be expected, that the slope of the lift curve decreases with an increase of the dihedral angle. Munk states that the steeper the lift curve of the stabilizer, the sooner does it reach its maximum lift coefficient and becomes ineffective. The stabilizer, in spite of its smaller angle of attack (as compared to the wing), when having a steep lift curve, may reach its maximum lift coefficient before the wings. The consequence would be a dangerous tendency of the airplane to nose up and to stall.[9]

It is of interest to notice that the zero lift for an airfoil set at zero yaw and zero dihedral occurs at the angle of attack of -5.4°, while the maximum lift occurs at the angle of attack of 15.6°, the effective range between those two values being 21.0°.

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9 M. M. Munk, The Principles of Aerodynamics, (Published by the Author, Washington, D.C., 1933) 252 pp.

This range for an airfoil set at the dihedral angles of 20° and of 40° is 23.2° and 28.2° respectively (Figures 7, 8 and 9). Another interesting fact is that the lift characteristics beyond the maximum lift are improved for an airfoil set at a dihedral angle. The requirement for the lift coefficient is that it should keep its value over a large range of the angles of attack, as near the maximum as possible. If the curve falls off, it should at least fall off gently and continuously, by no means sharply and suddenly.[10] A survey of Figures 7, 8, 9 and 10 shows that the curves at large dihedral angles have a greater tendency to remain unchanged at the stall. This tendency is even greater at large angles of yaw. A good example of this is given in Figure 9 ($\gamma = 40°$, $\psi = 20°$), where the lift curve, upon reaching its maximum value, falls off gently, and then gradually goes up, until it comes back approximately to its original maximum lift.

Drag Coefficient

The test results indicating the variation of drag coefficient with dihedral are shown in Figures 7, 8, 9 and 10. It is quite possible, however, that slight differences in the surface finish of the airfoil, and especially the interference effects, masked the true effect of the dihedral.

Regarding the influence of the disc of the model support on the

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[10] Ibid.

wings, it appears that the drag of the wings is increased, being even greater when the airfoil is set at a large angle of yaw. Betz[11] attributes this effect to two elements. The first element develops from the fact that by the presence of the disc the flow around the wing is so changed that the profile drag of the wing is no longer the same. The second element arises from the change in the induced drag of the wing. This element develops from the fact that through the presence of the disc the distribution of the lift along the wing undergoes a change and, in consequence, the induced drag is increased.

Due to the interference effects, the values of the drag coefficients, especially of the minimum drag coefficients, were increased. However, it could be said that at lift coefficients corresponding to cruising speeds, the drag coefficients at large dihedral angles do not differ much from those at zero dihedral. Additional experiments with a different supporting frame are necessary before any conclusions could be made.

Pitching Moment Coefficient

Wood[12] states that stability requires that an increased angle of attack result in changes in air forces so that their moment about the center of gravity is more diving (or less nosing up), and thus the angle of attack is reduced.

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[11] Betz, *op. cit.*

[12] K. D. Wood, *Technical Aerodynamics*, (New York: McGraw-Hill Book Company, Inc., 1935) 330 pp.

An examination of the pitching moment coefficients (taken about the 50 percent chord point) plotted against the angle of attack (Figures 12, 13, 14 and 15) shows that an increase in a positive dihedral results in a decrease of the positive slope of the pitching-moment curve. Thus, the slope of the pitching-moment curve at zero dihedral was + 0.0195, approximately the same as the slope at δ = - 20.° The slope was reduced to + 0.0145 at δ = + 20° and to + .0103 at δ = + 40.° This effect is favorable, since a decrease in slope to the graph of $C_{m_{c/2}}$ vs. α means that an increased angle of attack (and C_L) results in a decreased pitching moment, which reduces the angle of attack.

Rolling and Yawing Moment and Cross-Wind Force Coefficients

For the purpose of direct comparison, all three lateral-stability characteristics, that is the rolling moment, the yawing moment, and the cross-wind force, and their rates of change with respect to yaw, will be discussed under the same heading. Stable rolling and yawing moments and cross-wind force are defined to be such as to restore the wing to a condition of no yaw. Note that all moments refer to wind axes.

A survey of Figures 28, 29 and 30 reveals that a positive dihedral angle produces a stable rolling moment and an unstable yawing moment and cross-wind force. Negative dihedral resulted in stable yawing moment and unstable rolling moment and cross-wind force. All the yawing-moment coefficients are small in comparison with cross-wind force and rolling-moment coefficients of the same dihedral setting, but are approximately of the order of magnitude of the yawing-moment coefficients given by the rudder of a conventional airplane.[13] A more direct comparison of the effects of the dihedrals tested was made by computing the increments of rates of change due to dihedral angle, $\Delta\left(\frac{dC_l'}{d\psi}\right)_0$, $\Delta\left(\frac{dC_c'}{d\psi}\right)_0$, and $\Delta\left(\frac{dC_n'}{d\psi}\right)_0$, for 0° and 10° angles of attack and plotting them against the dihedral angle in Figure 31. This method of comparison was suggested by Shortal in TR 548.[14]

A further evaluation of $\Delta\left(\frac{dC_l'}{d\psi}\right)_0$, $\Delta\left(\frac{dC_c'}{d\psi}\right)_0$, and $\Delta\left(\frac{dC_n'}{d\psi}\right)_0$ is possible upon considering a straight line variation between these functions and the angle of dihedral. This variation is not sufficiently accurate for $\Delta\left(\frac{dC_n'}{d\psi}\right)_0$, for which function a parabolic variation would be more appropriate. It should also be noticed that for $\Delta\left(\frac{dC_c'}{d\psi}\right)_0$ negative dihedral angles produced the same unstable effects as positive dihedral angles. However, due to the uncertainty of these results, as well as those given in TR 548,[15] a straight line variation was found to be sufficiently justifiable in representing these functions.

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[13] H. L. Dryden and B. H. Monish, The Effect of Area and Aspect Ratio on the Yawing Moments of Rudders at Large Angles of Pitch of Three Fuselages, U.S. National Advisory Committee for Aeronautics, Technical Report No.437, 1932.

[14] Shortal, op. cit.

[15] Ibid.

It was found that the values of $\left(\frac{dC_{\ell}'}{d\psi}\right)_0$, $\left(\frac{dC_{c}'}{d\psi}\right)_0$, and $\left(\frac{dC_{n}'}{d\psi}\right)_0$ could be represented by empirical equations. These equations are:

$$\left(\frac{dC_{\ell}'}{d\psi}\right)_0 = 0.00025\,\gamma$$

$$\left(\frac{dC_{n}'}{d\psi}\right)_0 = 0.000055\,\gamma$$

$$\left(\frac{dC_{c}'}{d\psi}\right)_0 = 0.00035\,\gamma$$

Shortal[16] found corresponding values for [17] $\left(\frac{dC_{\ell}'}{d\psi}\right)_0$ and $\left(\frac{dC_{n}'}{d\psi}\right)_0$ to be 0.00033[18] and 0.000024. Bamber and House's value for $\left(\frac{dC_{\ell}'}{d\psi}\right)_0$ is 0.00021.

It should be added that the empirical equations given above are only approximate equations, and additional experiments are necessary before any definite conclusions concerning these functions could be made.

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16 Ibid.

17 Bamber and House, op. cit.

18 These values are per degree of dihedral.

Conclusions

Before any conclusions could be drawn it should be mentioned once more that the results of this investigation apply only to airfoils and that in making stability calculations the characteristics of the airplane as a whole must be very carefully taken into account. It should also be remembered that since the resultant force on the tail is a down force, the dihedral angle treated as a positive dihedral angle in this report is actually producing the effect of a negative dihedral angle.

The results of this investigation indicate that:

1. Increasing the dihedral of a V-shaped tail results in reduction in the slope of the lift curve and the maximum lift coefficient.

2. The value of minimum drag coefficient is affected by interference between the model and model support at large dihedral angles.

3. The effect of increasing the dihedral of a V-shaped tail is to produce stable pitching moments.

4. The effect of increasing the dihedral of a V-shaped tail is an increase in the stability characteristics of $\left(\frac{dC_{e'}}{d\psi}\right)_0$ by an amount equal to 0.00025 per degree, and a decrease in the stability characteristics of $\left(\frac{dC_{n'}}{d\psi}\right)_0$ and $\left(\frac{dC_{c'}}{d\psi}\right)_0$ by an amount equal to 0.000055 and 0.00035 per degree respectively.

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TABLE I

FORCE TESTS

$\gamma = 0°$

$\psi = -20°, -10°, 0°, 10°, 20°$

$\alpha°$	C_L	C_D	$C_{c'}$	$C_{e'}$	C_m	$C_{n'}$
						$\psi = 0°$
-7.5°	-0.175	0.038	0	0	-0.124	0
-4.0°	.100	.020	0	0	- .060	0
0°	.361	.032	0	0	.015	0
4°	.601	.058	0	0	.090	0
8°	.824	.090	0	0	.161	0
12°	1.012	.131	0	0	.221	0
15.6°	1.129	.173	0	0	.254	0
16°	1.119	.180	0	0	.256	0
17°	1.009	.208	0	0	.255	0
						$\psi = 10°$
-7°	-0.129	0.034	0.022	0	-0.082	0
-3°	.150	.024	.008	0.0021	- .031	0
0°	.213	.030	.007	.0042	.016	-0.0005
2°	.462	.041	.0075	.0057	.055	-.0009
5°	.640	.060	.0095	.0051	.109	-.0018
9°	.854	.092	.013	.0068	.182	-.0031
13°	1.045	.133	.0196	.0119	.239	-.0049
16°	1.108	.170	.018	.0142	.292	-.0069
17°	1.062	.196	.015	—	.292	-.0070

TABLE I (CONT.)

α	C_L	C_D	C_c'	C_ℓ'	C_m	C_n'
						$\psi=20°$
-6°	-0.100	0.030	0.019	0.0043	-0.061	-0.0015
-4°	.031	.024	.015	.0059	-.044	-.0020
-2°	.159	.022	.013	.0067	-.016	-.0026
2°	.396	.035	.016	.0079	.054	-.0032
6°	.612	.058	.025	.0083	.125	-.0066
10°	.811	.089	.032	.0103	.200	-.0100
13°	.994	.118	.048	.0141	.245	-.0139
16°	1.065	.152	.053	.0218	.277	-.0159
17°	1.074	.210	.052	.0241	.277	-.0156
18°	1.012	—	.050	.0252	—	-.0150
						$\psi=-10°$
-7°	-0.129	0.034	-0.016	0	-0.082	0
-3°	.150	.024	-.010	-0.0039	-.031	0
0°	.213	.030	-.012	-.0047	.015	0.0002
2°	.462	.041	-.013	-.0044	.055	.0010
5°	.640	.060	-.016	-.0041	.109	.0026
9°	.854	.092	-.023	-.0040	.182	.0051
13°	1.045	.133	-.032	-.0077	.239	.0091
16°	1.108	.170	-.035	-.0122	.292	.0128
17°	1.062	.196	-.033	-.0103	.292	.0130
						$\psi=-20°$
-6°	-0.100	0.030	-0.019	-0.0048	-0.061	0
-4°	.031	.024	-.015	-.0061	-.044	0
-2°	.159	.022	-.015	-.0075	-.016	0.0002
2°	.396	.035	-.018	-.0098	.054	.0019
6°	.612	.058	-.026	-.0078	.125	.0058
10°	.811	.089	-.037	-.0086	.200	.0103
13°	.994	.118	-.049	-.0127	.245	.0150
16°	1.065	.152	-.061	-.0193	.277	.0189
17°	1.074	.210	-.060	-.0208	.277	.0188
18°	1.012	—	-.059	-.0204	—	.0172

TABLE II

FORCE TESTS

$\gamma = 20°$

$\psi = -20°, -10°, 0°, 10°, 20°$

α	C_L	C_D	$C_{c'}$	$C_{e'}$	C_m	$C_{n'}$
						$\psi = 0°$
-7°	-0.118	0.040	0	0	-0.081	0
-4°	.058	.034	0	0	-.036	0
-1°	.224	.040	0	0	.005	0
3°	.438	.060	0	0	.060	0
7°	.633	.090	0	0	.112	0
11°	.820	.128	0	0	.155	0
15°	.976	.170	0	0	.182	0
18°	1.052	.212	0	0	.195	0
20°	.850	.262	0	0	.151	0
						$\psi = 10°$
-7°	-0.096	0.051	-0.038	0.0428	-0.046	0.0129
-3°	.114	.038	-.048	.0432	.004	.0128
0°	.300	.044	-.050	.0445	.045	.0120
2°	.401	.052	-.051	.0461	.072	.0114
5°	.559	.072	-.049	.0492	.109	.0103
9°	.752	.104	-.046	.0503	.161	.0080
13°	.919	.142	-.039	.0516	.194	.0036
15°	.961	.166	-.029	.0472	.200	0
16°	.850	.208	-.007	.0285	.174	-.0028

TABLE II (CONT.)

α	C_L	C_D	$C_{c'}$	$C_{e'}$	C_m	$C_{n'}$
						$\psi = 20°$
-7°	-0.060	0.076	-0.072	0.0728	0.078	0.0202
-4°	.103	.058	-.079	.0767	.101	.0201
-2°	.210	.054	-.083	.0784	.119	.0200
2°	.412	.063	-.086	.0808	.166	.0190
6°	.600	.085	-.082	.0836	.216	.0166
10°	.760	.116	-.065	.0823	.251	.0120
12°	.831	.135	-.043	.0760	.261	.0053
13°	.804	.153	-.025	.0682	.211	-.0020
						$\psi = -10°$
-7°	-0.096	0.051	0.036	-0.0412	-0.046	-0.0150
-3°	.114	.038	.036	-.0423	.004	-.0131
0°	.300	.044	.034	-.0428	.045	-.0128
2°	.401	.052	.033	-.0424	.072	-.0105
5°	.559	.072	.029	-.0418	.109	-.0088
9°	.752	.104	.023	-.0409	.161	-.0057
13°	.919	.142	.011	-.0395	.194	-.0021
15°	.961	.166	.004	-.0360	.200	-.0009
16°	.850	.208	.001	-.0160	.174	+.0014
						$\psi = -20°$
-7°	-0.060	0.076	0.062	-0.0721	0.078	-0.0243
-4°	.103	.058	.071	-.0762	.101	-.0230
-2°	.210	.054	.076	-.0780	.119	-.0219
2°	.412	.063	.081	-.0802	.166	-.0192
6°	.600	.085	.076	-.0800	.216	-.0169
10°	.760	.116	.054	-.0761	.251	-.0116
12°	.831	.135	.033	-.0689	.261	-.0050
13°	.804	.153	.015	-.0607	.211	+.0033

TABLE III

FORCE TESTS

$\gamma = 40^\circ$

$\psi = -20^\circ, -10^\circ, 0^\circ, 10^\circ, 20^\circ$

α	C_L	C_D	$C_{c'}$	$C_{e'}$	C_m	$C_{n'}$
						$\psi = 0^\circ$
-6°	-0.092	0.038	0	0	-0.044	0
-4°	-.010	.035	0	0	-.022	0
0°	.143	.040	0	0	.018	0
4°	.293	.055	0	0	.055	0
12°	.510	.108	0	0	.106	0
16°	.641	.138	0	0	.121	0
20°	.772	.168	0	0	.092	0
24°	.768	.209	0	0	.076	0
26°	.741	.244	0	0	—	0
						$\psi = 10^\circ$
-8°	-0.100	0.090	-0.150	0.0680	0.049	0.0270
-4°	.011	.067	-.151	.069	.055	.0268
0°	.141	.059	-.151	.069	.066	.0252
4°	.293	.068	-.150	.068	.088	.0228
8°	.431	.091	-.145	.067	.125	.0183
12°	.541	.116	-.135	.066	.138	.0138
16°	.621	.144	-.115	.062	.132	.0081
18°	.635	.162	-.090	.049	.120	.0030
20°	.505	—	—	—	.109	-.0059

TABLE III (CONT.)

α	C_L	C_D	$C_{c'}$	$C_{l'}$	C_m	$C_{n'}$
						$\psi = 20°$
-8°	0.014	0.139	-0.216	0.100	0.171	0.0490
-4°	.090	.131	-0.263	.117	.200	.0461
0°	.181	.122	-.294	.130	.219	.0401
4°	.290	.119	-.298	.132	.225	.0318
8°	.423	.127	-.284	.130	.225	.0222
12°	.392	.183	-.181	.087	.215	.0138
16°	.347	.193	-.176	.060	.161	.0081
20°	.355	.211	-.088	.044	.125	-.0059
24°	.382	.236	-.054	.032	.106	—
28°	.408	.268	—	—	—	—
						$\psi = -10°$
-8°	-0.100	0.090	0.146	-0.072	0.049	-0.0231
-4°	.011	.067	.150	-.072	.055	-.0259
0°	.141	.059	.151	-.072	.066	-.0260
4°	.293	.068	.151	-.071	.088	-.0251
8°	.431	.091	.148	-.070	.125	-.0230
12°	.541	.116	.137	-.072	.138	-.0190
16°	.621	.144	.113	-.072	.132	-.0122
20°	.505	—	0	0	.109	+.0008
						$\psi = -20°$
-8°	0.014	0.139	0.230	-0.104	0.171	-0.0470
-4°	.090	.131	.280	-.124	.200	-.0477
0°	.181	.122	.315	-.139	.219	-.0455
4°	.290	.119	.330	-.146	.225	-.0402
8°	.423	.127	.319	-.146	.225	-.0350
12°	.392	.183	.241	-.139	.215	-.0171
16°	.347	.193	.150	-.079	.161	+.0032
20°	.355	.211	.111	-.062	.125	—
24°	.382	.236	—	—	.106	—
28°	.408	.268	—	—	—	—

TABLE IV

FORCE TESTS

$\gamma = -20°$

$\psi = -20°, -10°, 0°, 10°, 20°$

α	C_L	C_D	$C_{c'}$	$C_{\ell'}$	C_m	$C_{n'}$
						$\psi = 0°$
-7.5°	-0.120	0.034	0	0	-0.107	0
-4°	.099	.023	0	0	-.044	0
0°	.334	.030	0	0	.035	0
4°	.559	.050	0	0	.112	0
8°	.768	.072	0	0	.188	0
12°	.962	.104	0	0	.258	0
15.5°	1.069	.195	0	0	.307	0
16°	1.065	.200	0	0	.307	0
18°	.921	.224	0	0	.245	0
20°	.824	.251	0	0	.185	0
22°	.780	.280	0	0	.154	0
						$\psi = 10°$
-7°	-0.111	0.048	-0.039	-0.0400	-0.099	-0.0070
-4°	.072	.034	-.038	-.0398	-.064	-.0062
0°	.309	.034	-.037	-.0395	.014	-.0053
3°	.476	.045	-.034	-.0380	.072	-.0050
6°	.631	.062	-.029	-.0361	.129	-.0048
10°	.823	.090	-.020	-.0338	.203	-.0046
13.5°	.949	.122	-.007	-.0200	.261	-.0042
16°	.894	.184	+.061	+.0245	.245	-.0045
18°	.879	.248	—	.0392	.239	-.0045
20°	.823	.273	—	.0465	.250	-.0048

TABLE IV (CONT.)

α	C_L	C_D	$C_{c'}$	$C_{\ell'}$	C_m	$C_{n'}$
						$\psi = 20°$
-7°	-0.179	0.080	-0.080	-0.0675	-0.205	-0.0143
-4°	0	.057	-.080	-.0680	-.164	-.0125
0°	.221	.046	-.079	-.0670	-.094	-.0102
3°	.378	.050	-.076	-.0655	-.036	-.0091
6°	.322	.061	-.066	-.0625	+.022	-.0082
10°	.703	.086	-.045	-.0545	.100	-.0078
12°	.769	.104	-.023	-.0450	.126	-.0075
14°	.739	.178	+.036	+.0200	.104	-.0075
17°	.752	.212	.086	.0100	.165	-.0077
20°	.802	.251	.123	.0180	.206	-.0080
						$\psi = -10°$
-7°	-0.111	0.048	0.038	0.0369	-0.099	0.0041
-4°	.072	.034	.037	.0321	-.064	.0039
0°	.309	.034	.035	.0301	.014	.0032
3°	.476	.045	.025	.0312	.072	.0038
6°	.631	.062	.025	.0321	.129	.0048
10°	.823	.090	.016	.0301	.203	.0061
13.5°	.949	.122	-.023	.0120	.261	.0075
16°	.894	.184	-.095	-.0215	.245	.0081
18°	.879	.248	—	-.0379	.239	.0083
20°	.823	.273	—	-.0520	.250	.0086
						$\psi = -20°$
-7°	-0.179	0.080	0.077	0.0649	-0.205	0.0107
-4°	0	.057	.077	.0643	-.164	.0081
0°	.221	.046	.070	.0638	-.094	.0070
3°	.378	.050	.065	.0618	-.036	.0073
6°	.322	.061	.057	.0580	.022	.0080
10°	.703	.086	.044	.0530	.100	.0096
12°	.769	.104	.020	.0442	.126	.0103
14°	.739	.178	-.048	.0422	.104	.0112
17°	.752	.212	-.143	-.0110	.165	.0126
20°	.802	.251	-.174	-.0345	.206	.0133

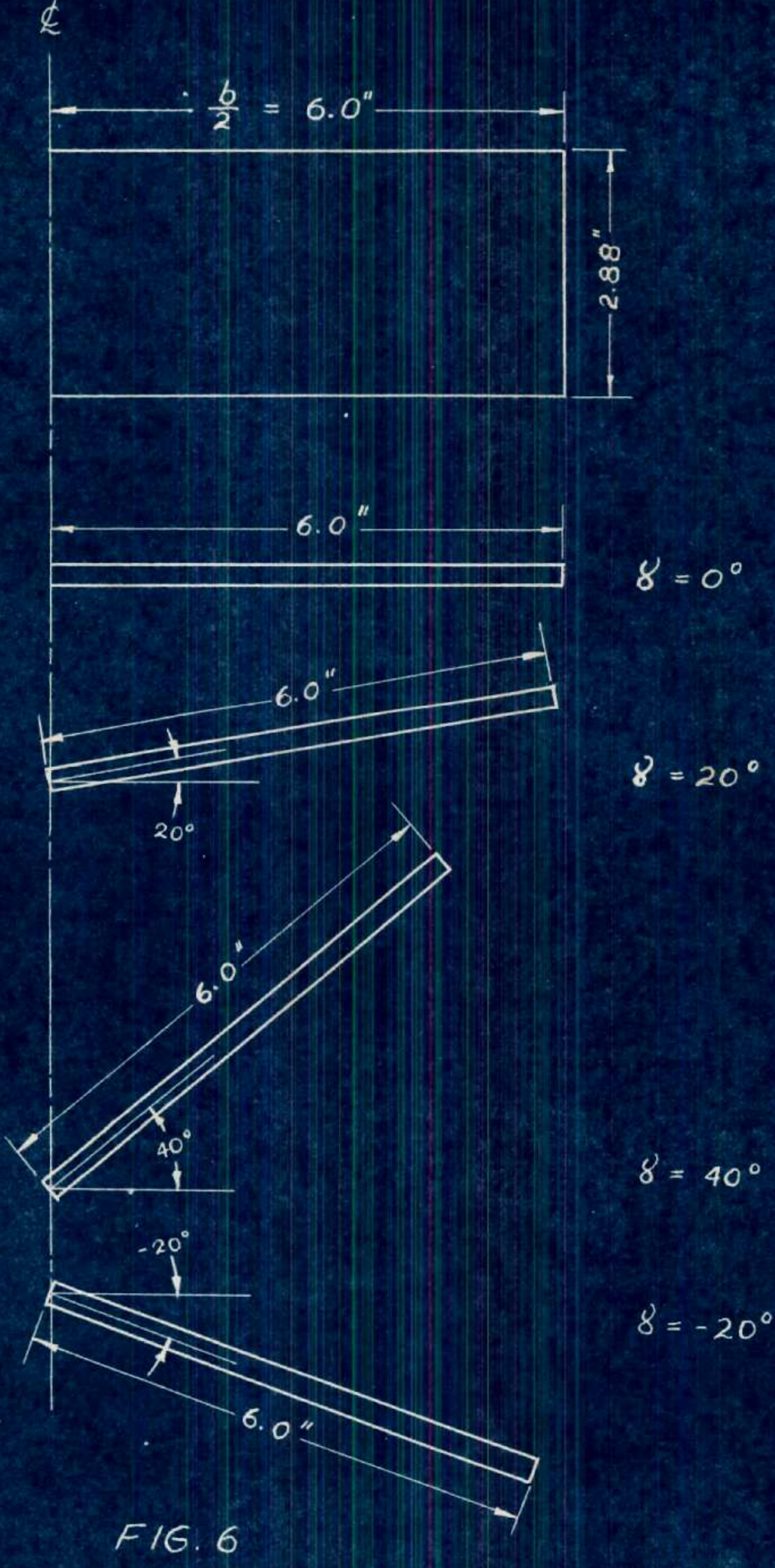


FIG. 6
DIMENSIONS OF THE MODEL

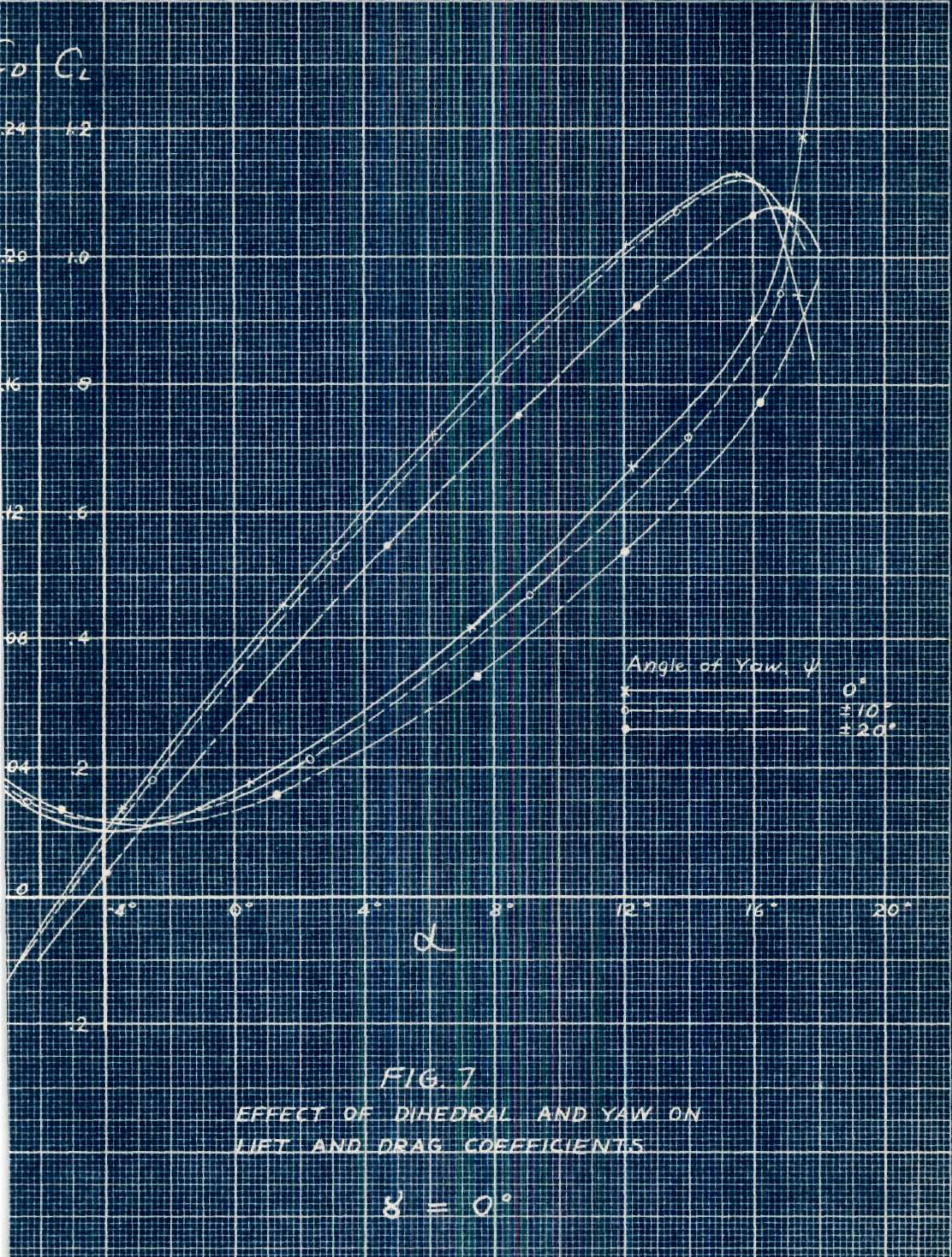


FIG. 7
EFFECT OF DIHEDRAL AND YAW ON LIFT AND DRAG COEFFICIENTS

$\delta = 0°$

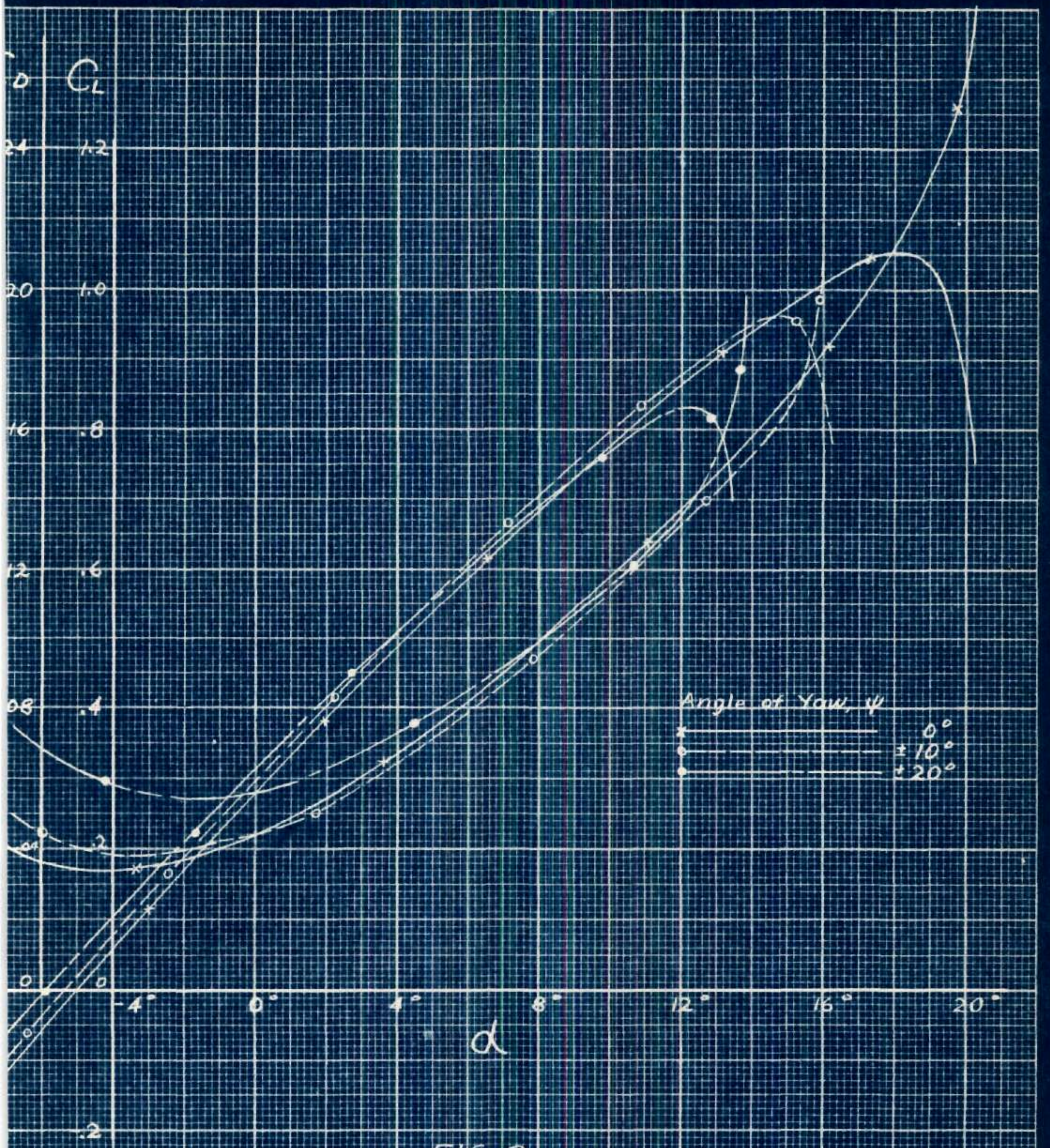


FIG. 8
EFFECT OF DIHEDRAL AND YAW ON
LIFT AND DRAG COEFFICIENTS
$\gamma = +20°$

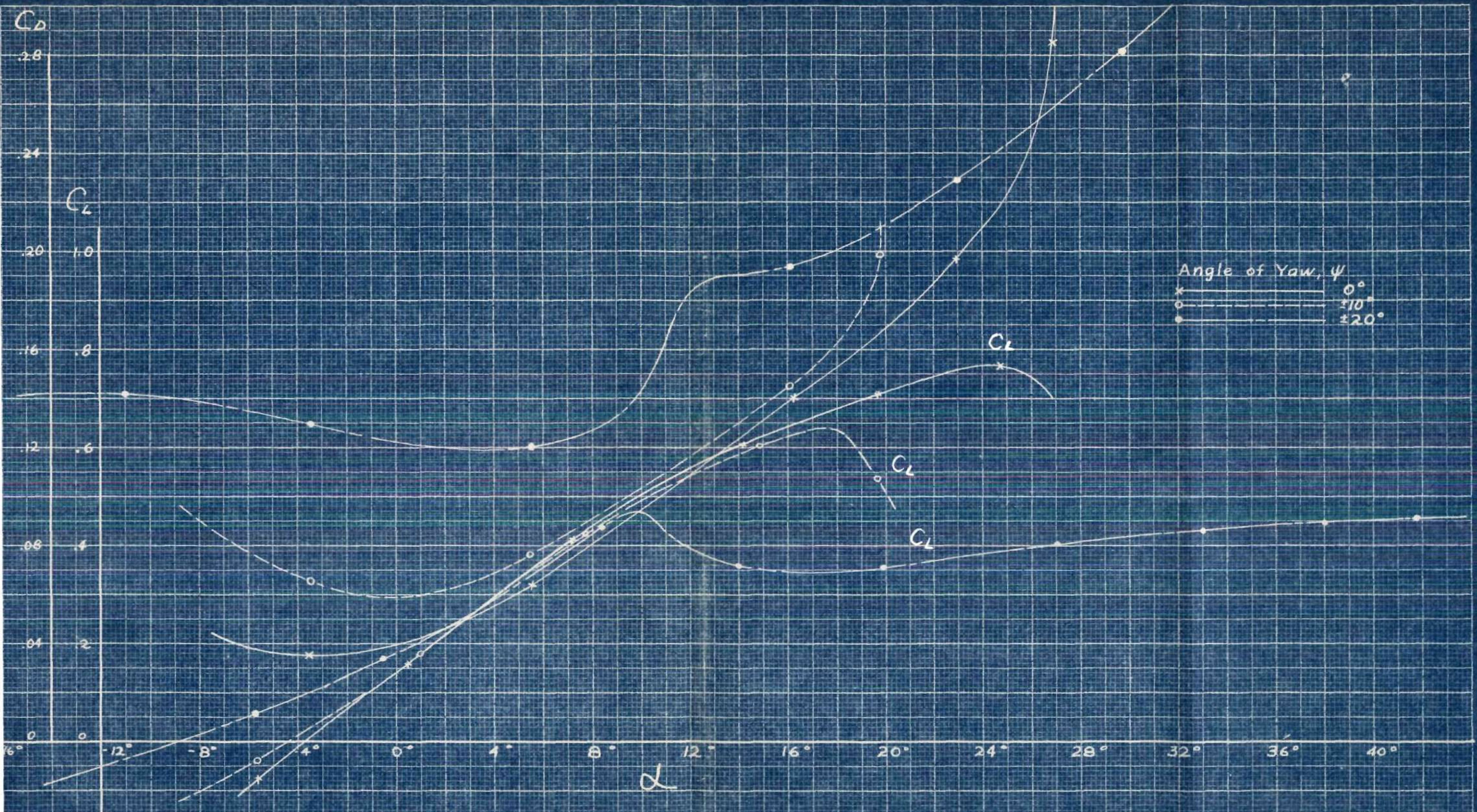


FIG. 9

EFFECT OF DIHEDRAL AND YAW ON LIFT AND DRAG COEFFICIENTS

$\delta = +40°$

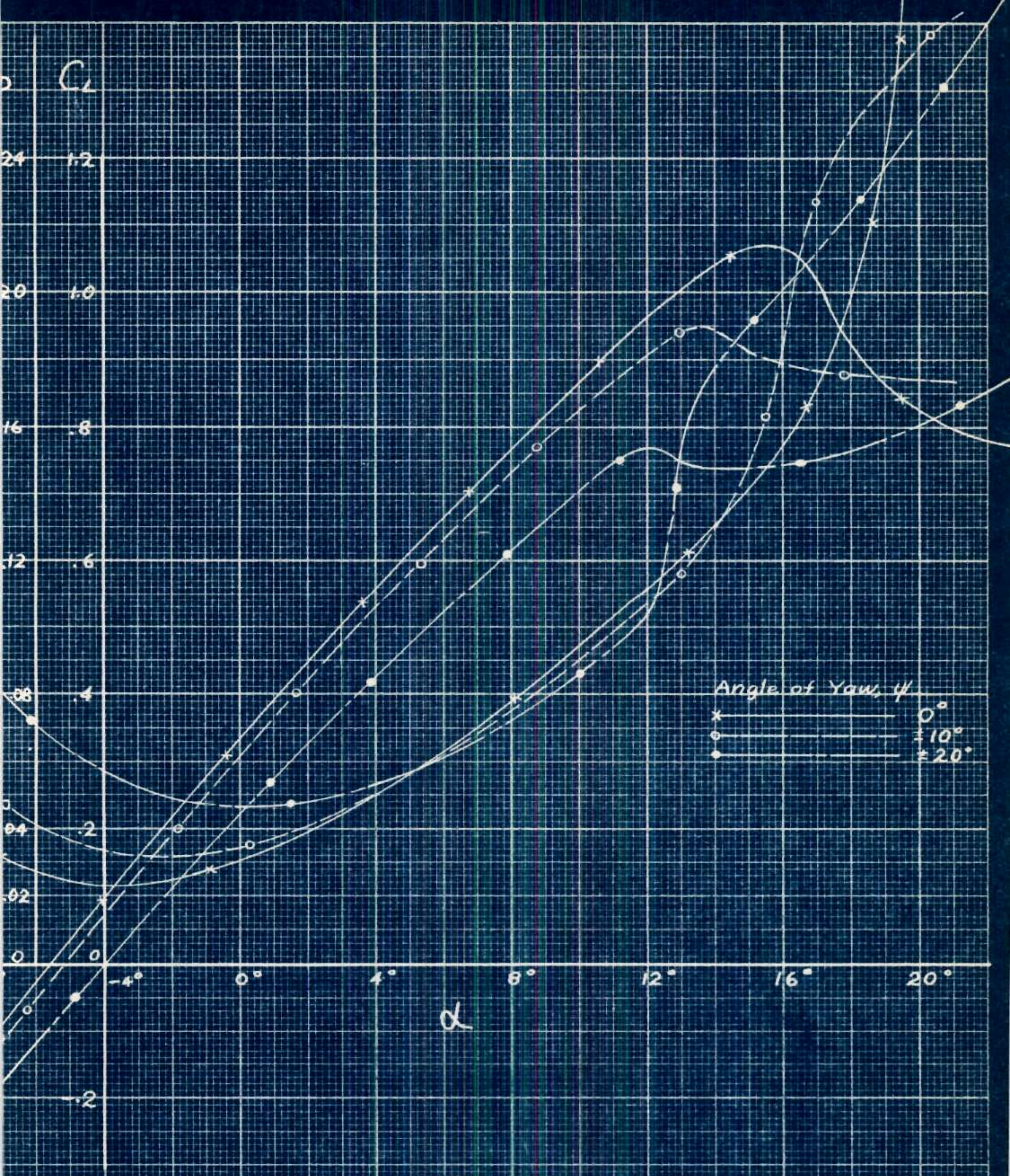


FIG. 10
EFFECT OF DIHEDRAL AND YAW ON
LIFT AND DRAG COEFFICIENTS
$\delta = -20°$

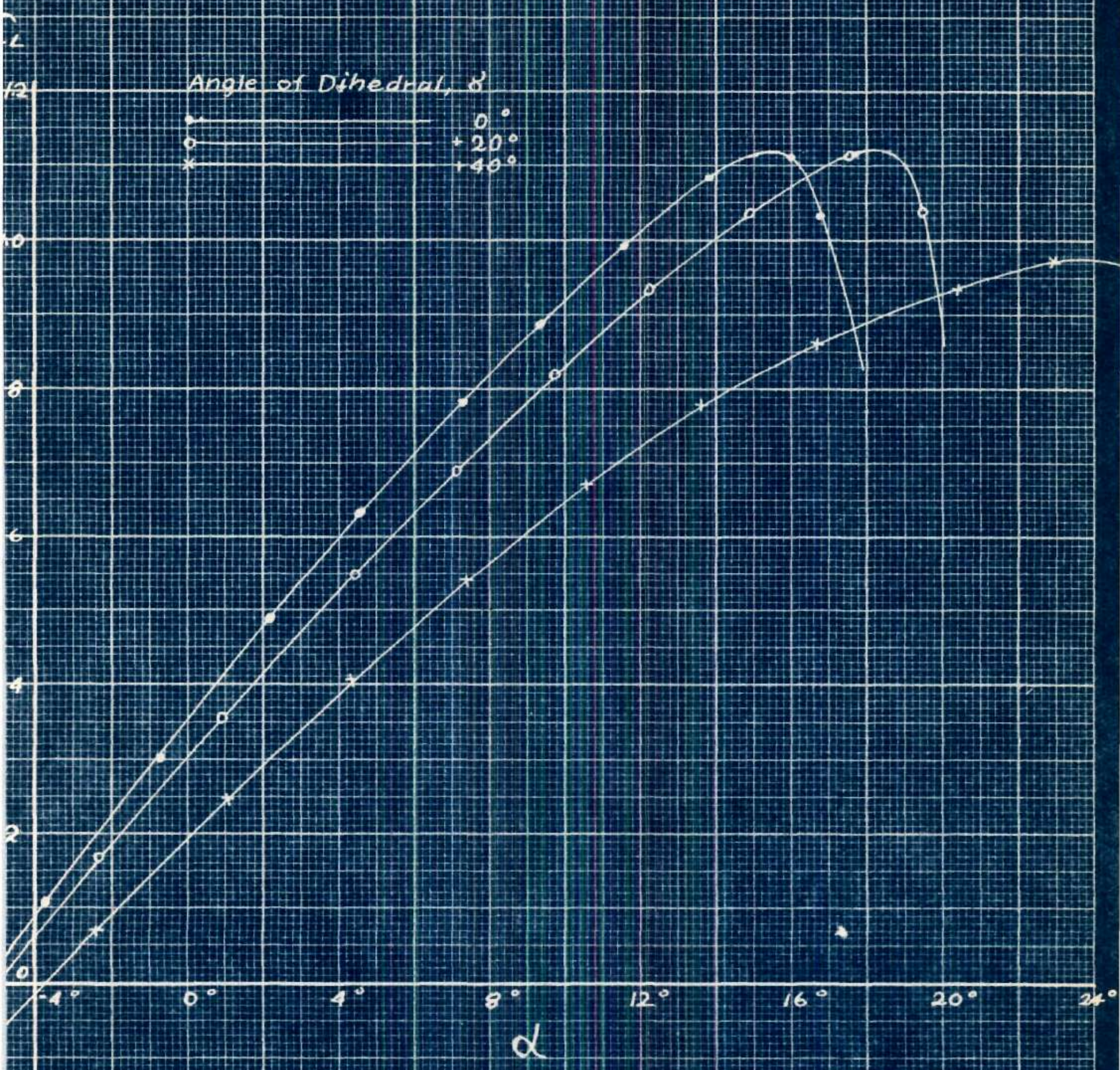


FIG. 11

EFFECT OF DIHEDRAL ON LIFT COEFFICIENT

(Corrected for the reduction in projected area)

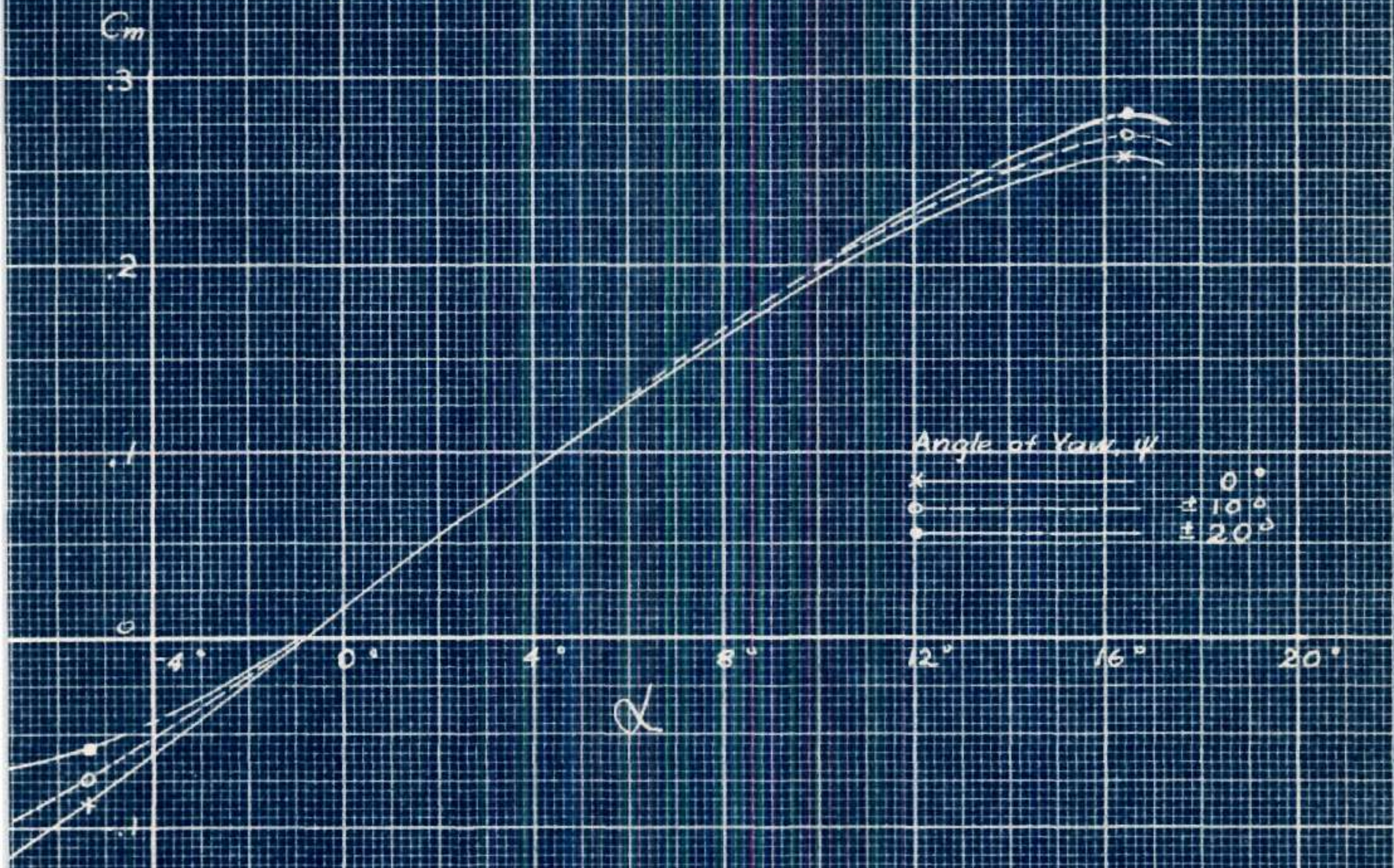


FIG. 12
EFFECT OF DIHEDRAL AND YAW ON
PITCHING-MOMENT COEFFICIENT

$\delta = 0°$

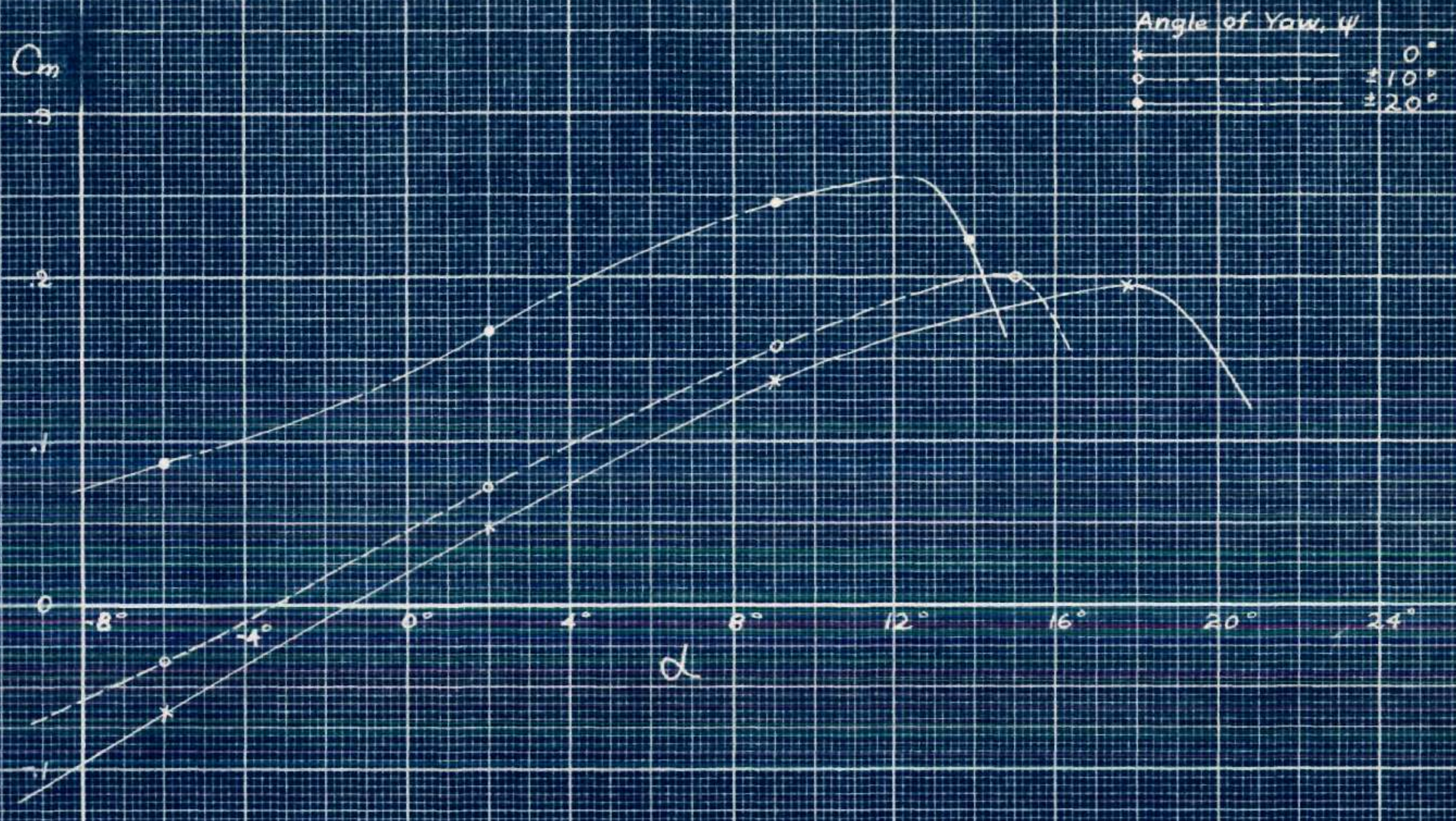


FIG. 13
EFFECT OF DIHEDRAL AND YAW ON PITCHING-MOMENT COEFFICIENT

$\gamma = +20°$

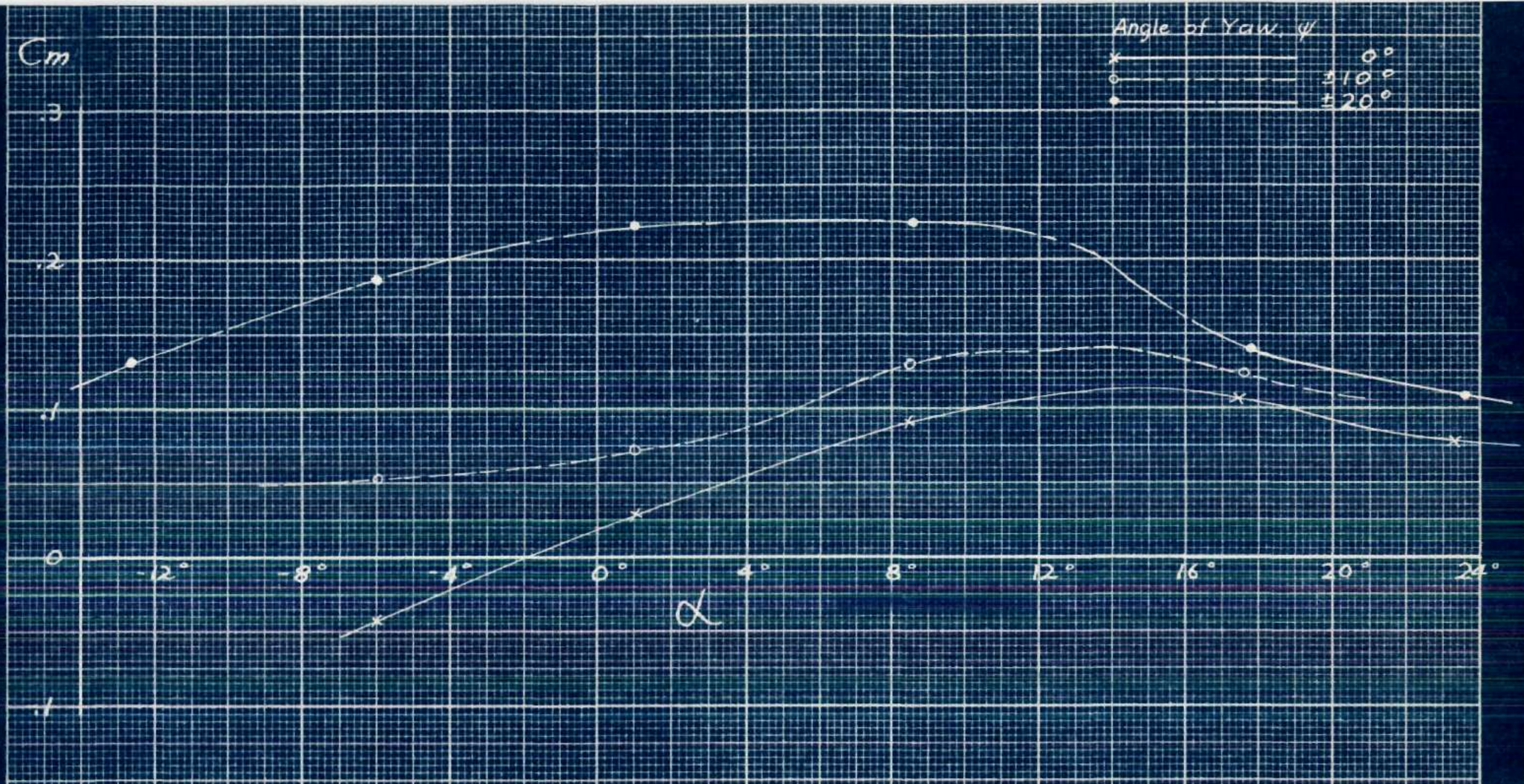


FIG. 14
EFFECT OF DIHEDRAL AND YAW ON
PITCHING-MOMENT COEFFICIENT

$\delta = +40°$

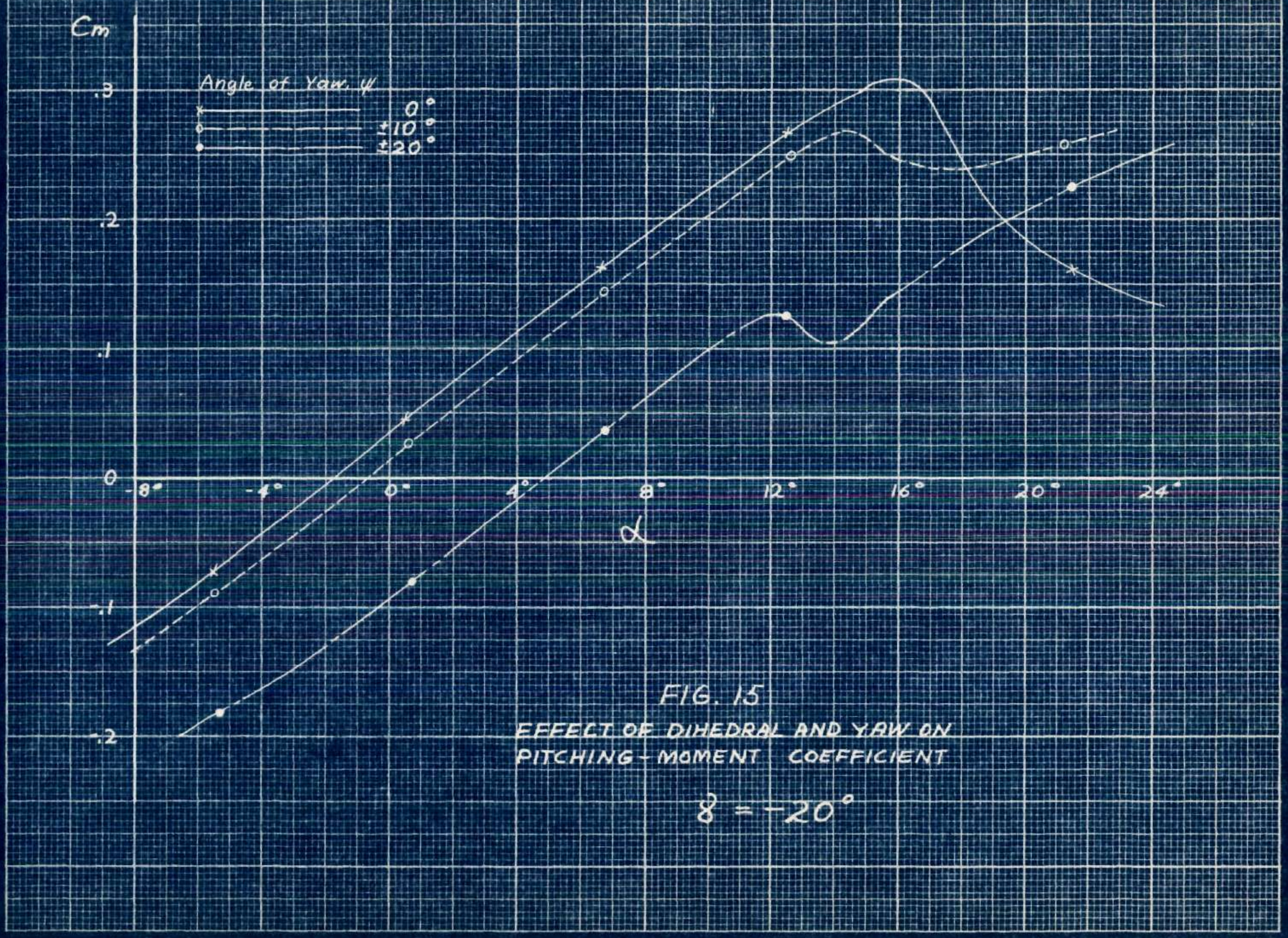


FIG. 15

EFFECT OF DIHEDRAL AND YAW ON PITCHING-MOMENT COEFFICIENT

$\delta = -20°$

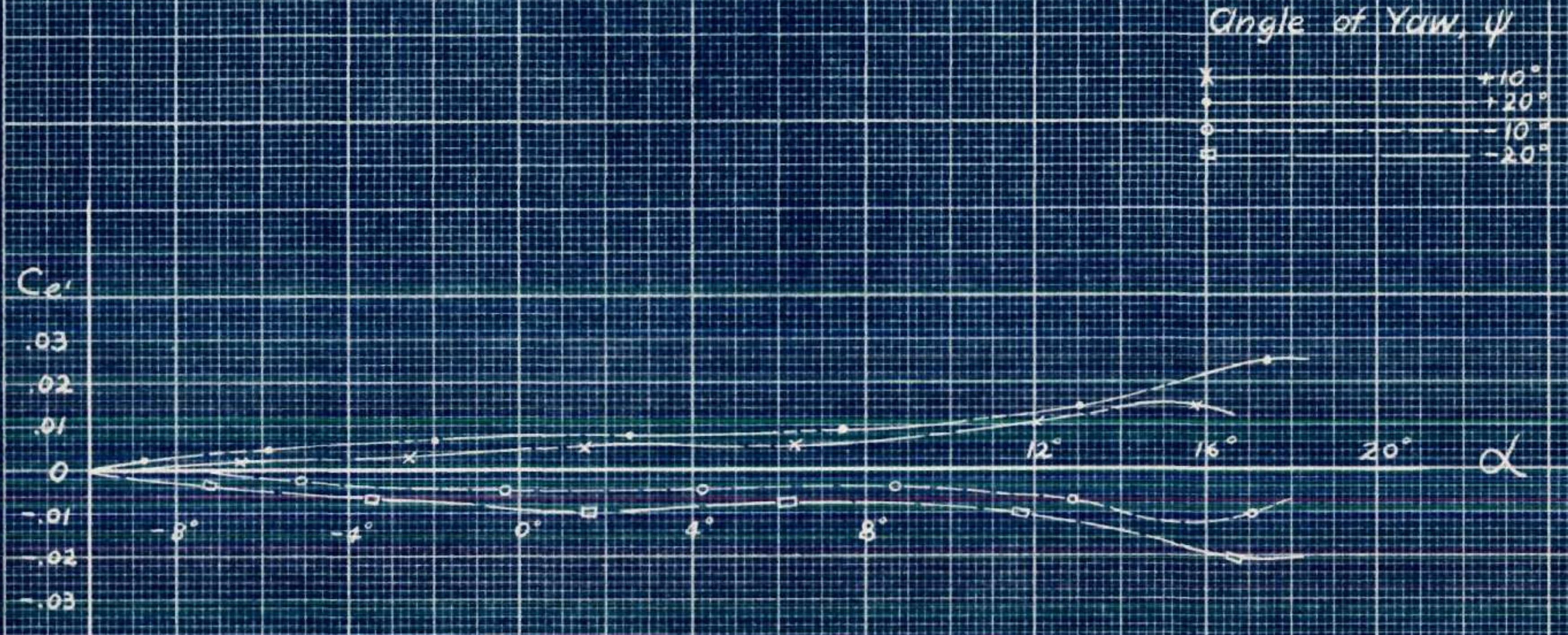


FIG. 16

EFFECT OF DIHEDRAL AND YAW ON ROLLING-MOMENT COEFFICIENT

$\gamma = 0°$

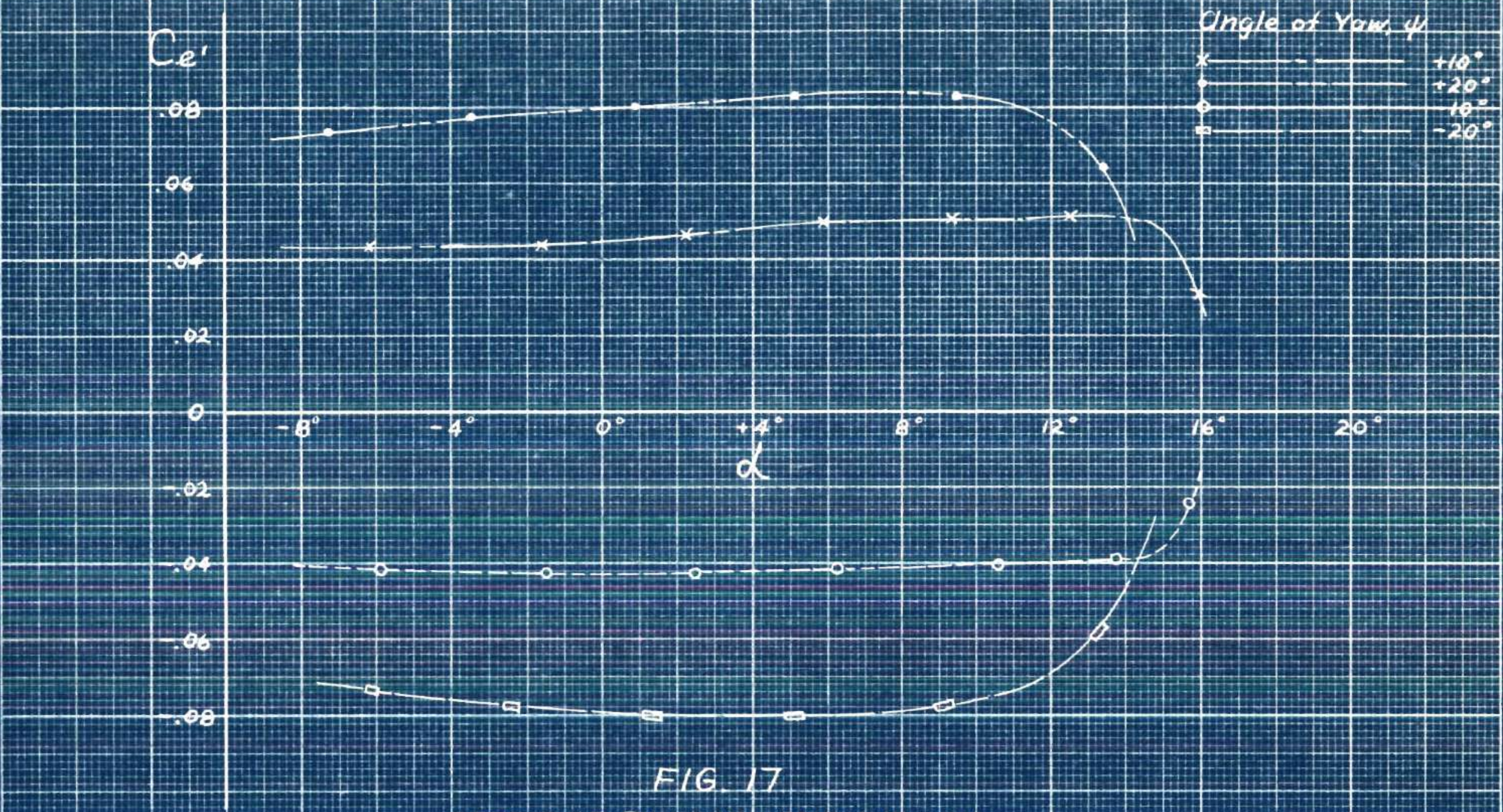
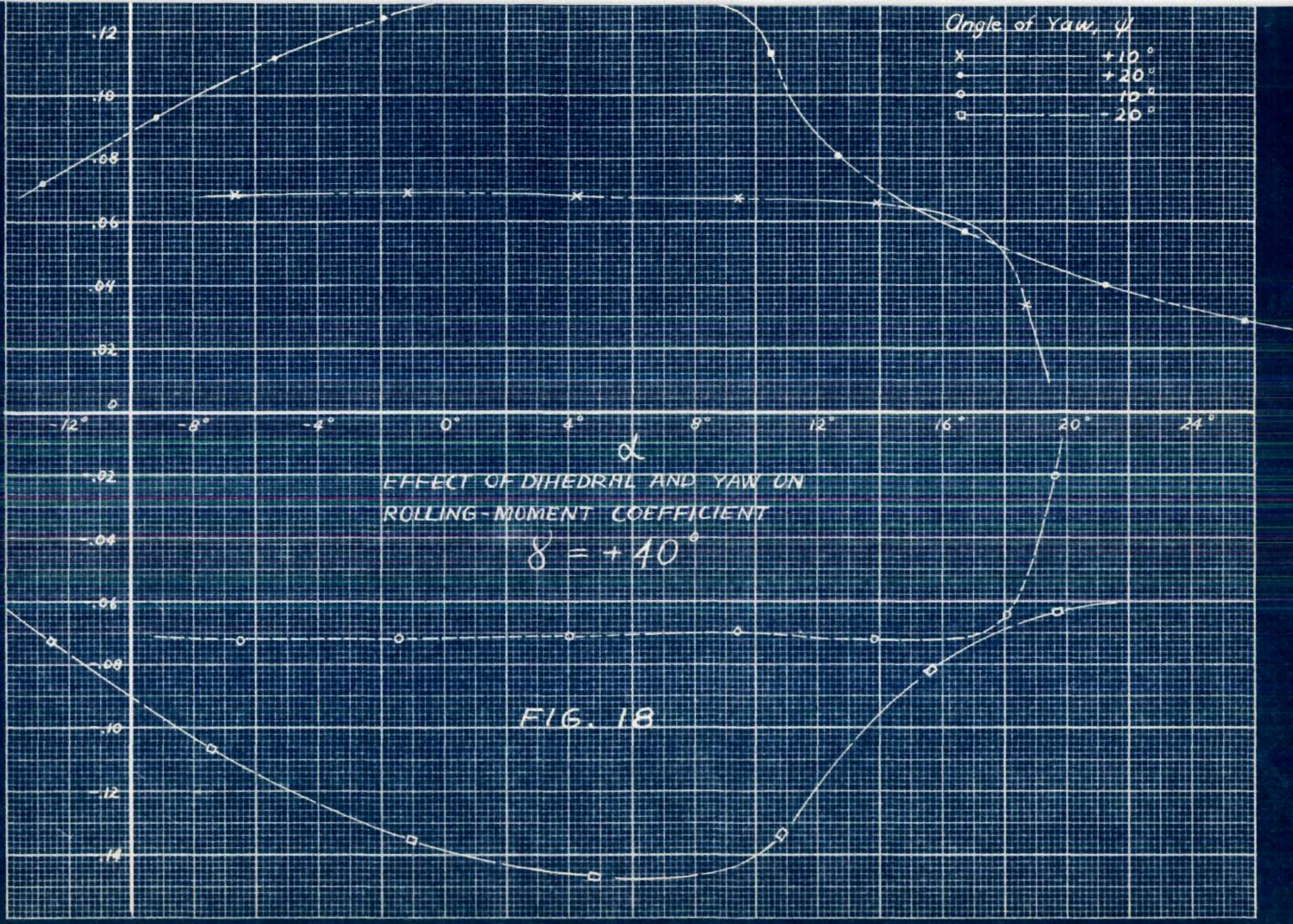


FIG. 17

EFFECT OF DIHEDRAL AND YAW ON ROLLING-MOMENT COEFFICIENT

$\gamma = +20°$



EFFECT OF DIHEDRAL AND YAW ON ROLLING-MOMENT COEFFICIENT

$\delta = +40°$

FIG. 18

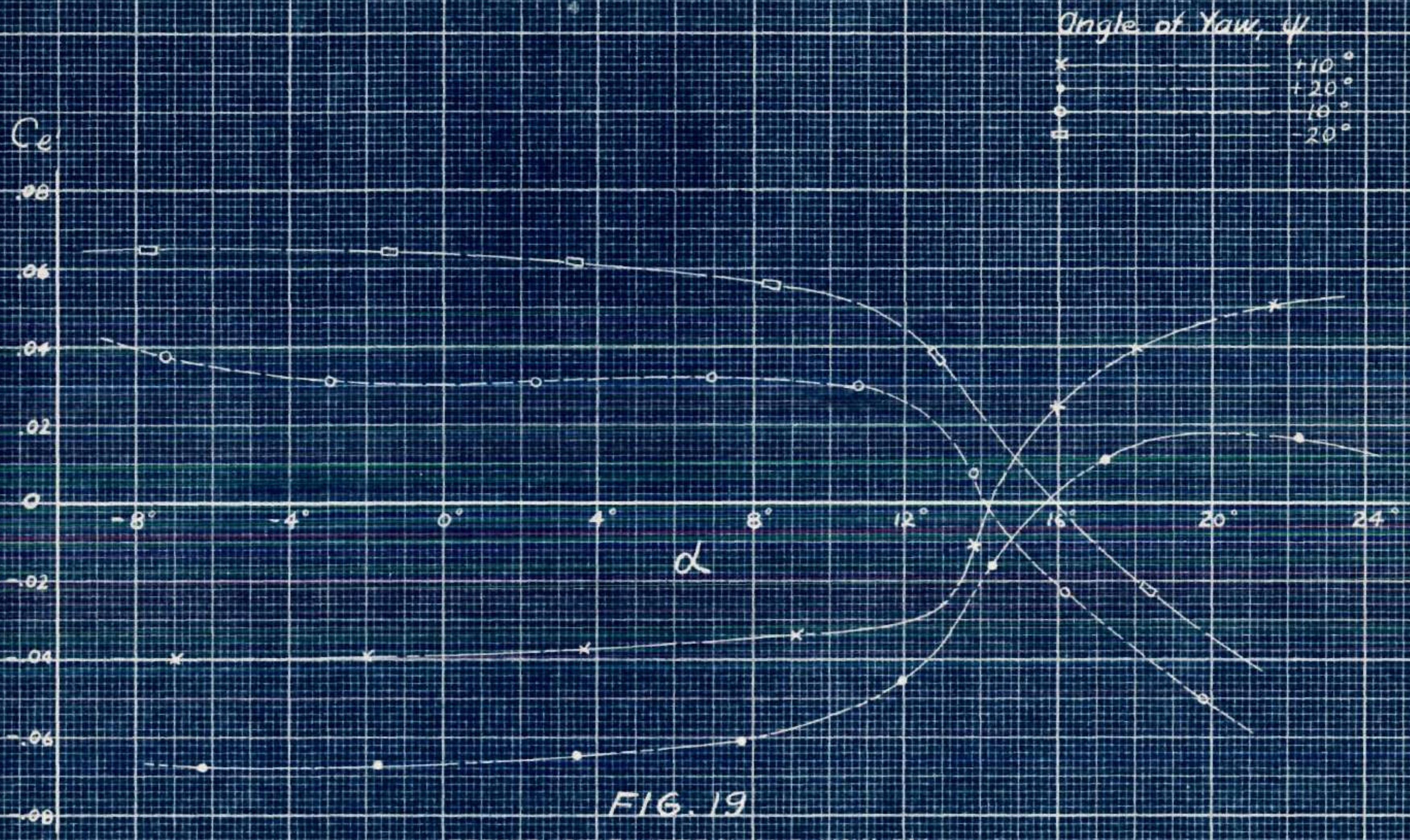


FIG. 19

EFFECT OF DIHEDRAL AND YAW ON ROLLING-MOMENT COEFFICIENT

$\gamma = -20°$

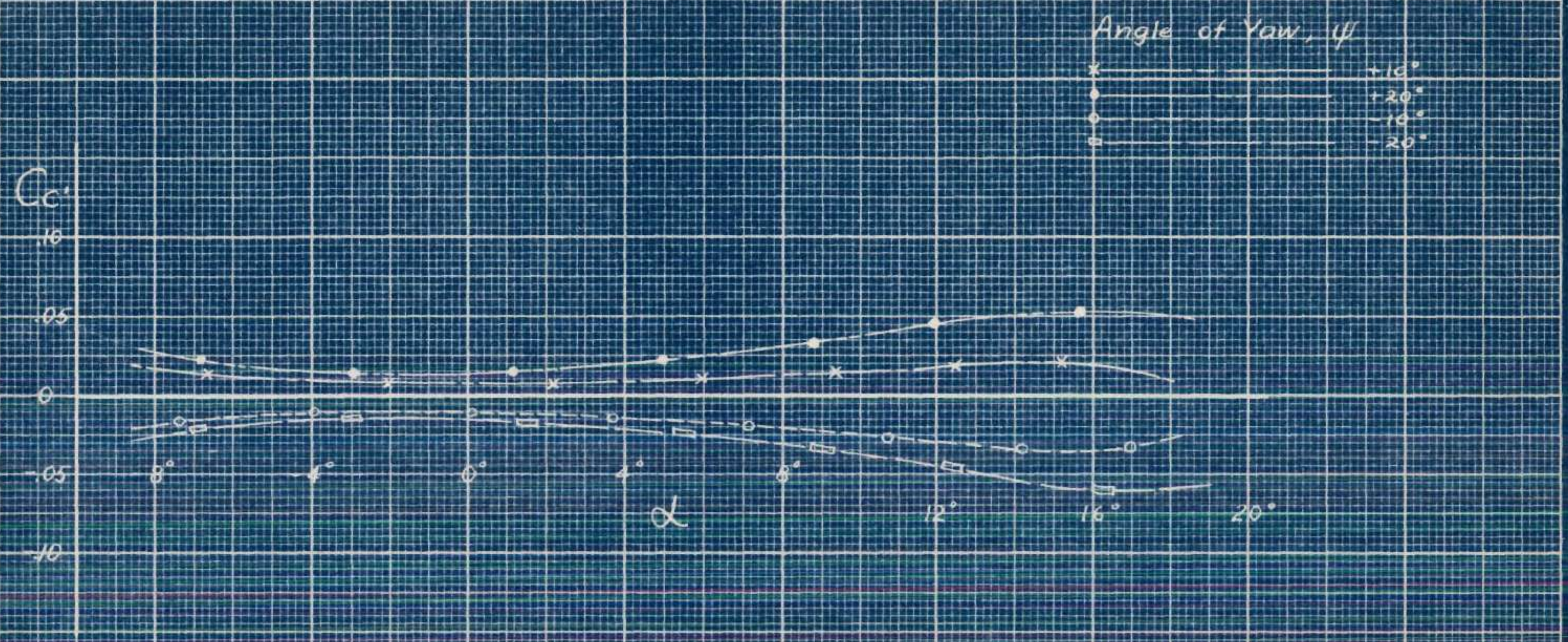


FIG. 20

EFFECT OF DIHEDRAL AND YAW ON CROSS-WIND FORCE COEFFICIENT

$\delta = 0°$

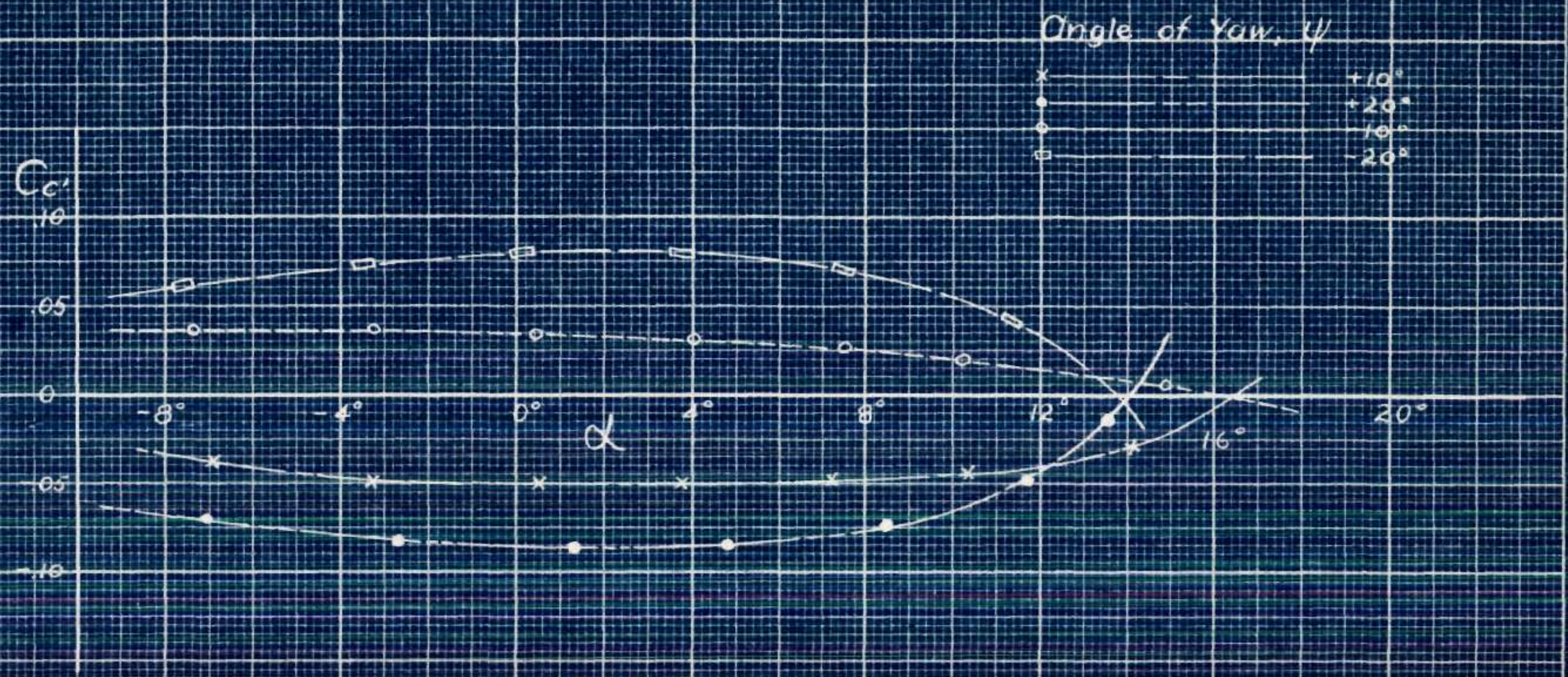


FIG. 21

EFFECT OF DIHEDRAL AND YAW ON CROSS-WIND FORCE COEFFICIENT

$\gamma = +20°$

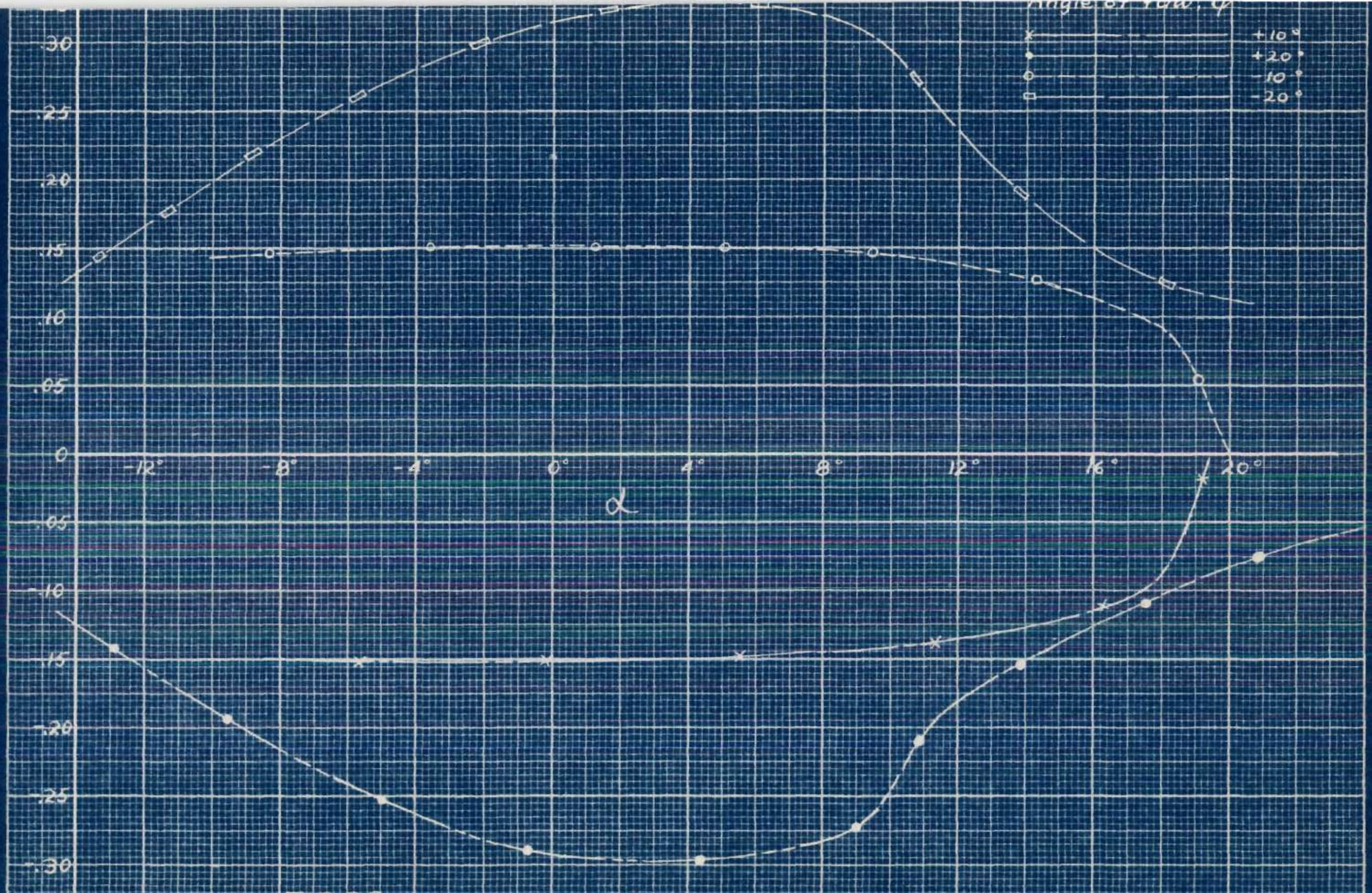


FIG. 22 EFFECT OF DIHEDRAL AND YAW ON CROSS-WIND FORCE COEFFICIENT

$\gamma = +40°$

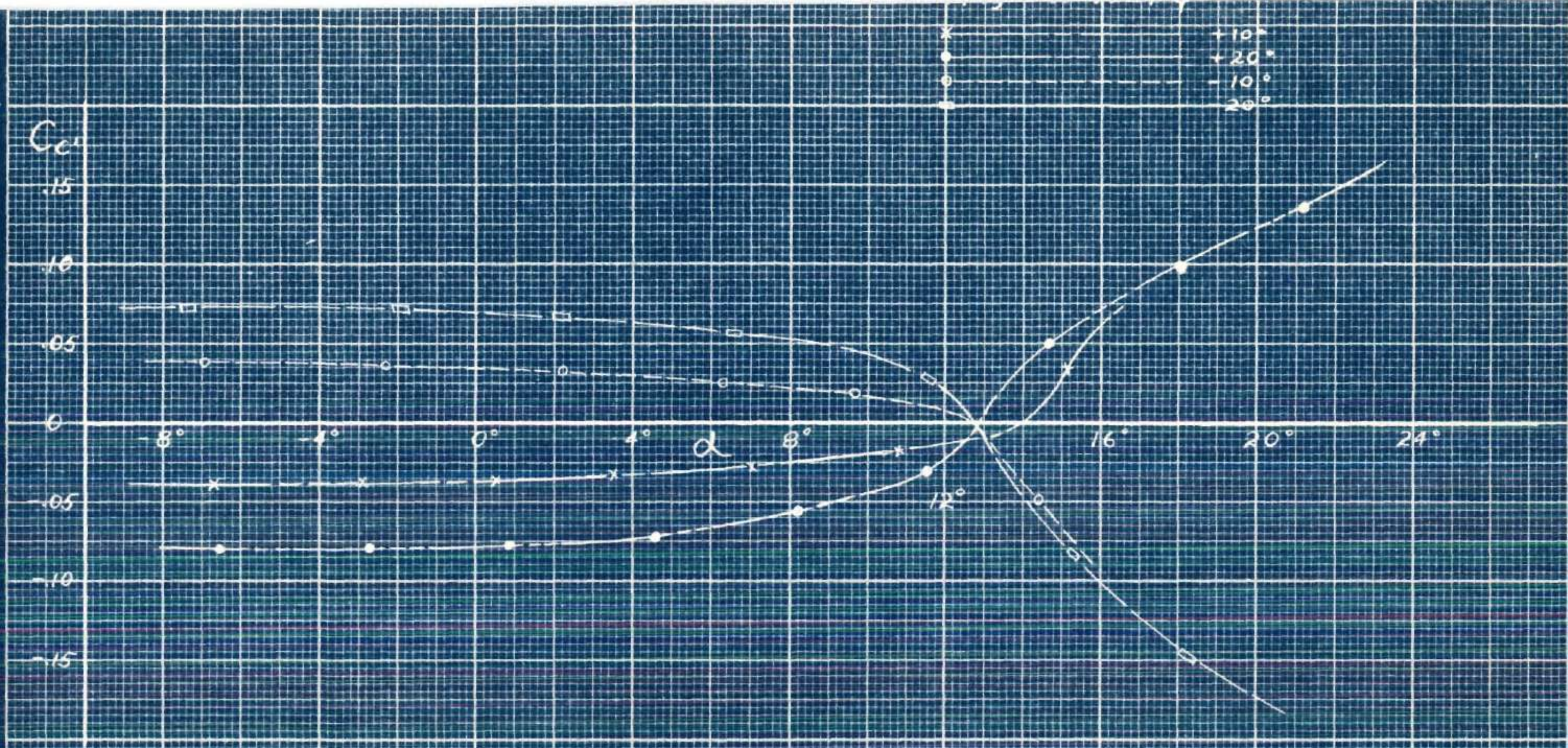


FIG. 23
EFFECT OF DIHEDRAL AND YAW ON
CROSS-WIND FORCE COEFFICIENT
$\gamma = -20°$

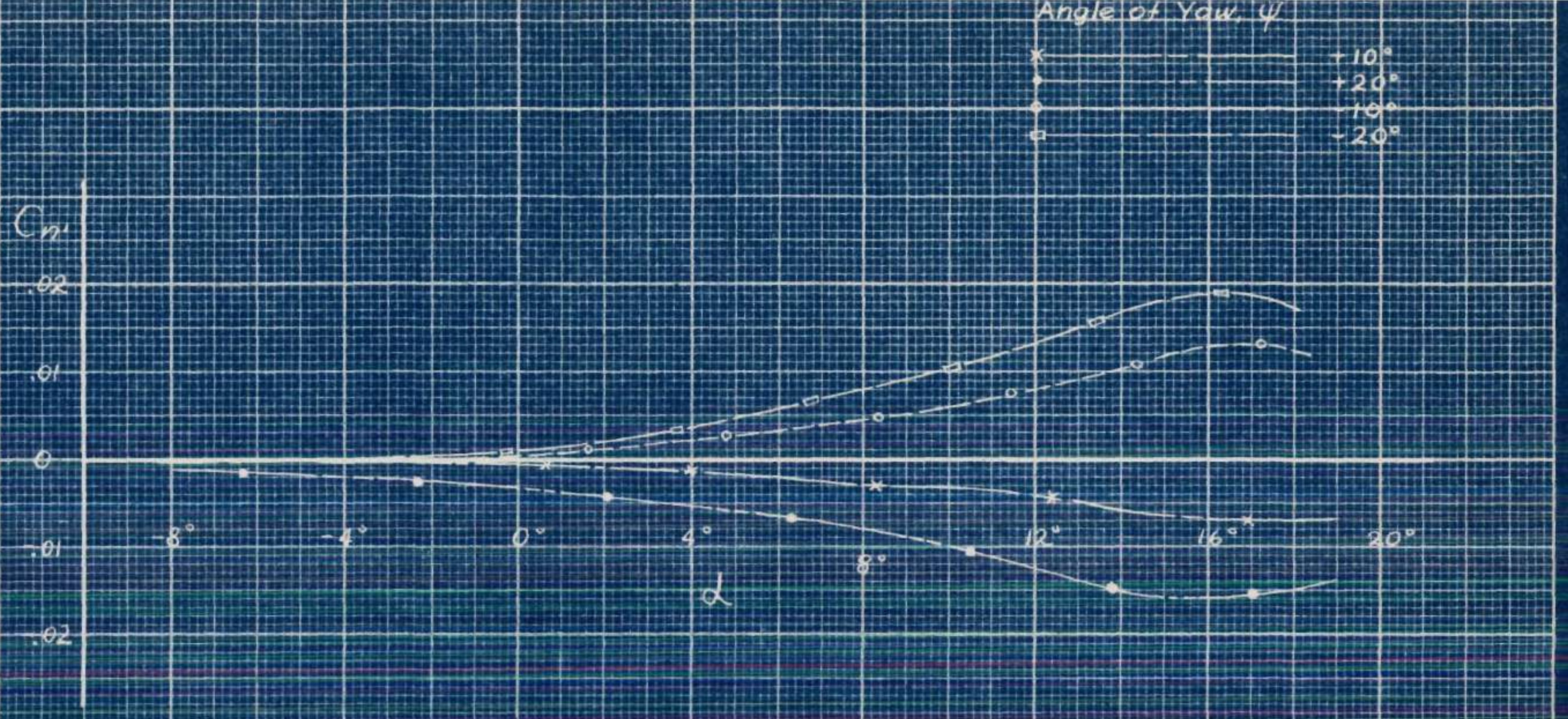


FIG. 24

EFFECT OF DIHEDRAL AND YAW ON
YAWING-MOMENT COEFFICIENT

$\gamma = 0°$

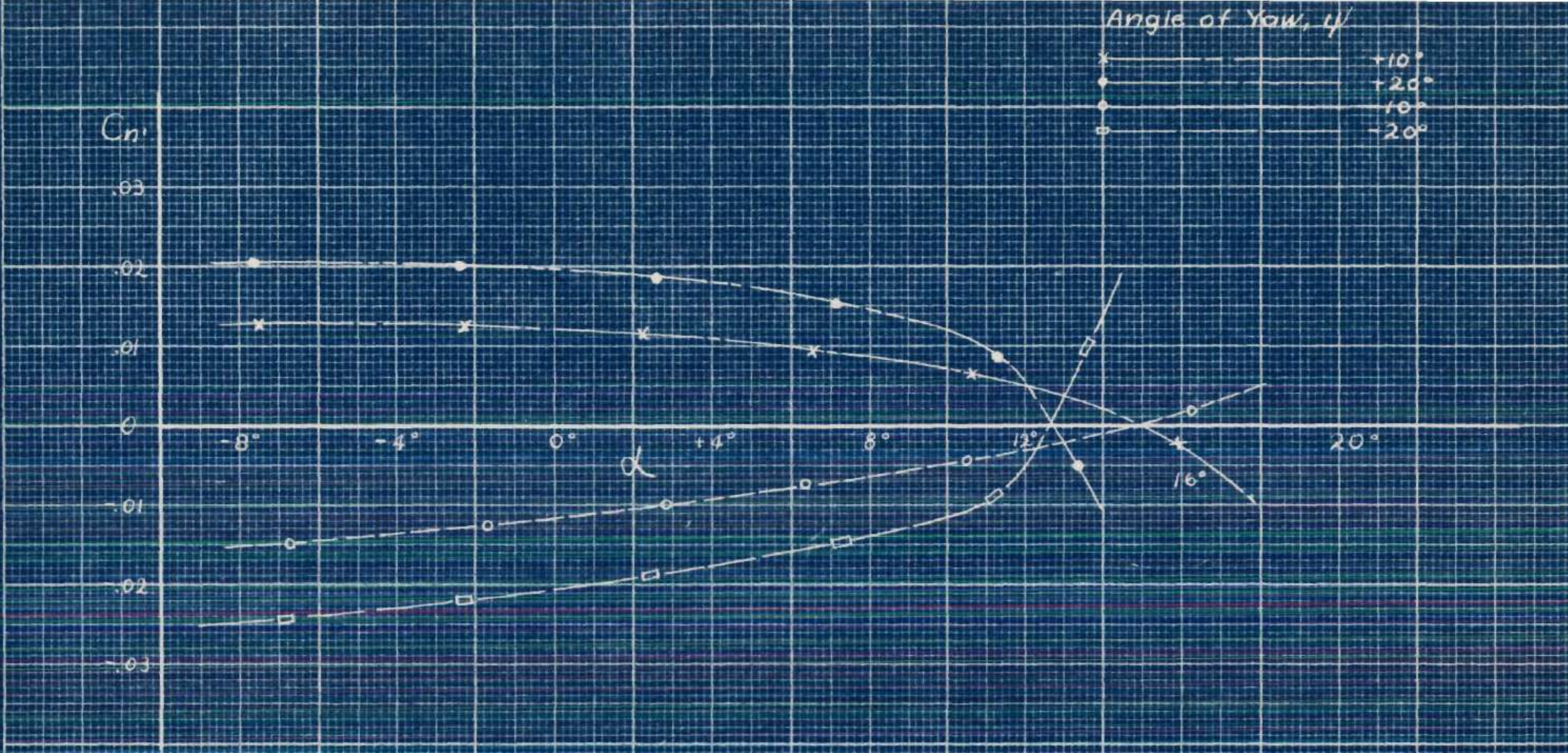


FIG. 25

EFFECT OF DIHEDRAL AND YAW ON YAWING-MOMENT COEFFICIENT

$\gamma = +20°$

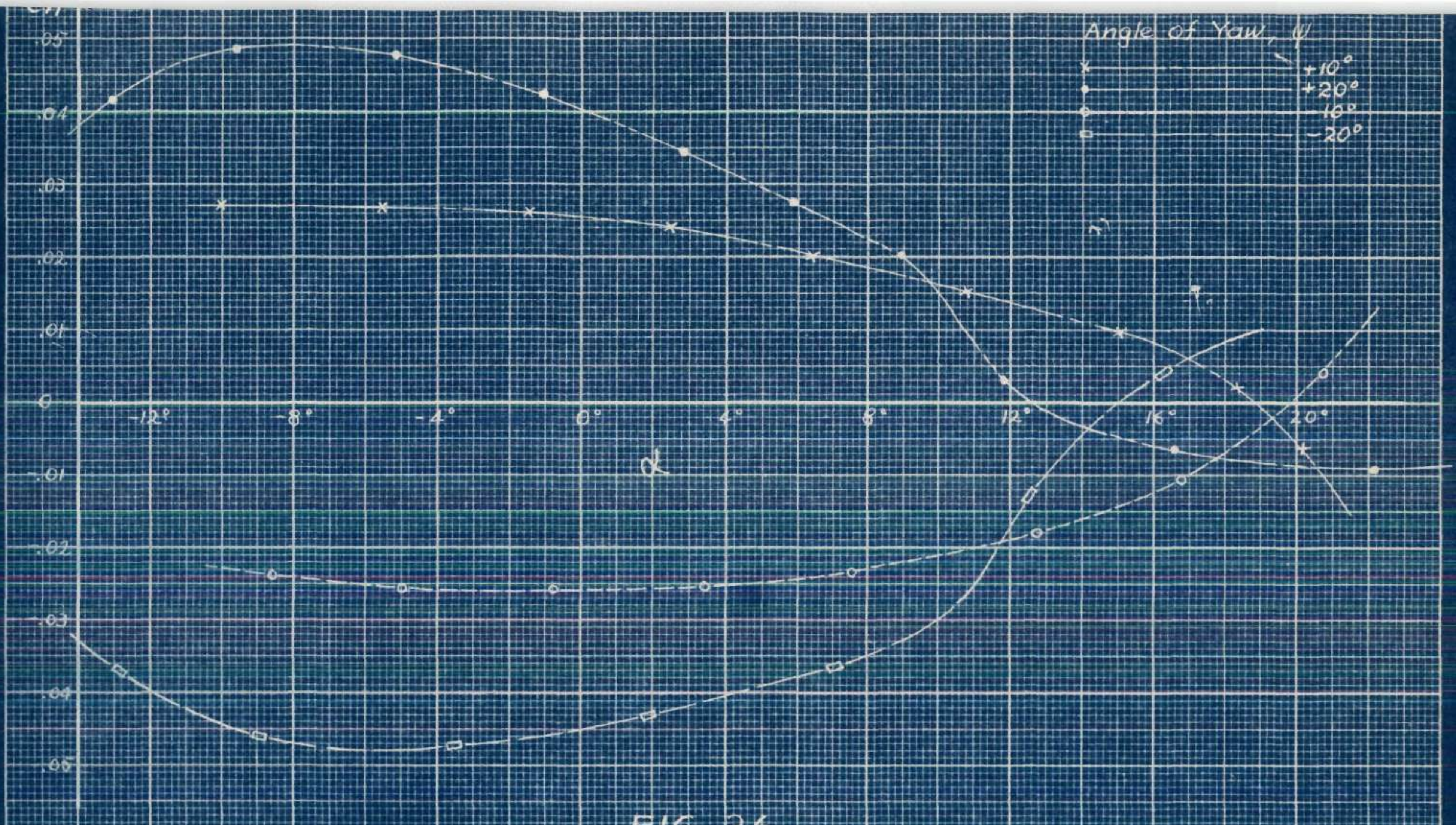


FIG. 26

EFFECT OF DIHEDRAL AND YAW ON YAWING-MOMENT COEFFICIENT

$\gamma = +40°$

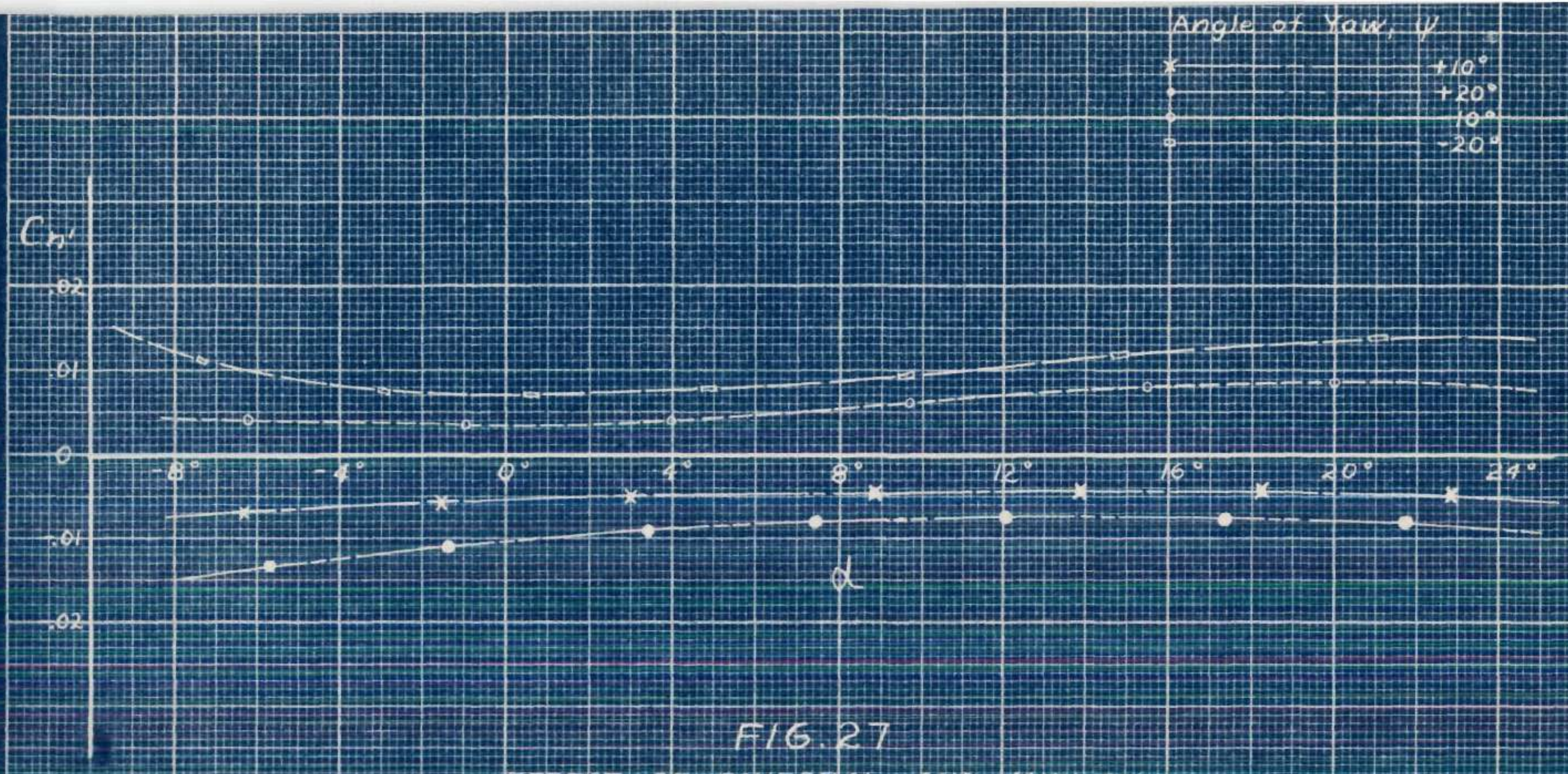


FIG. 27

EFFECT OF DIHEDRAL AND YAW ON YAWING-MOMENT COEFFICIENT

$\gamma = -20°$

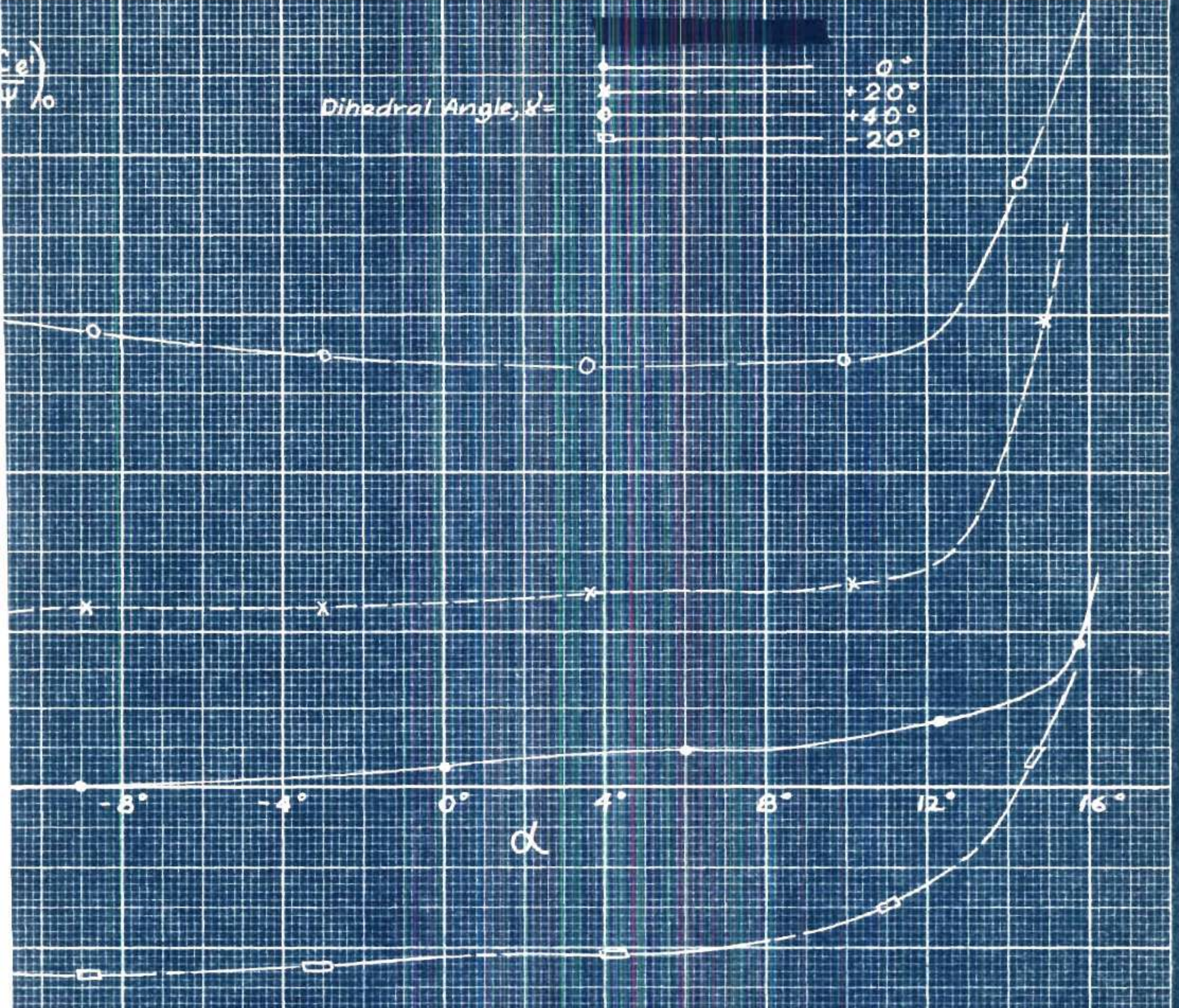


FIG. 28
EFFECT OF DIHEDRAL ON RATE OF CHANGE OF ROLLING-MOMENT COEFFICIENT WITH ANGLE OF YAW

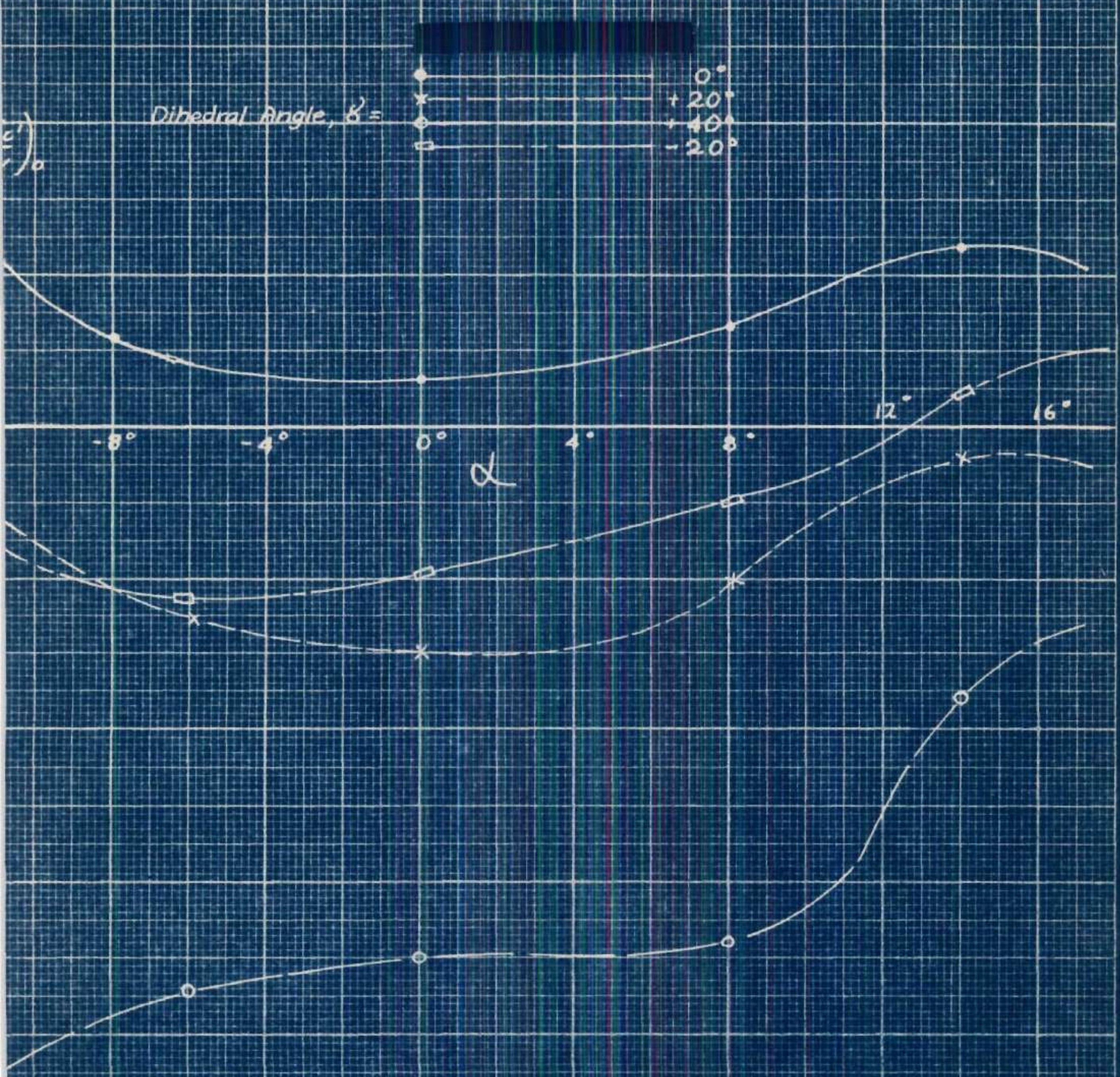


FIG. 29

EFFECT OF DIHEDRAL ON RATE OF CHANGE OF CROSS-WIND FORCE COEFFICIENT WITH ANGLE OF YAW

[redacted]

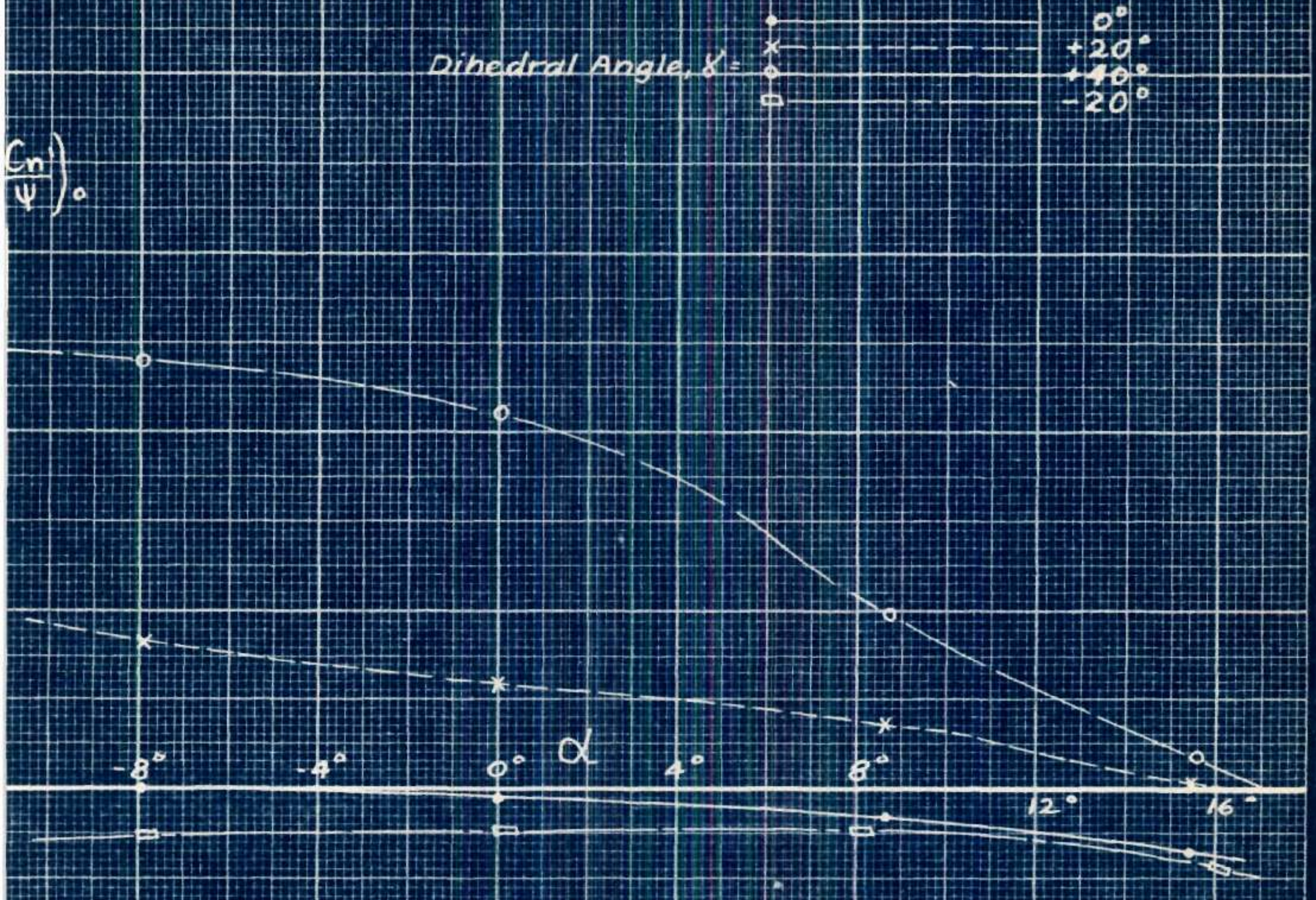


FIG. 30
EFFECT OF DIHEDRAL ON RATE OF CHANGE OF YAWING-MOMENT COEFFICIENT WITH ANGLE OF YAW

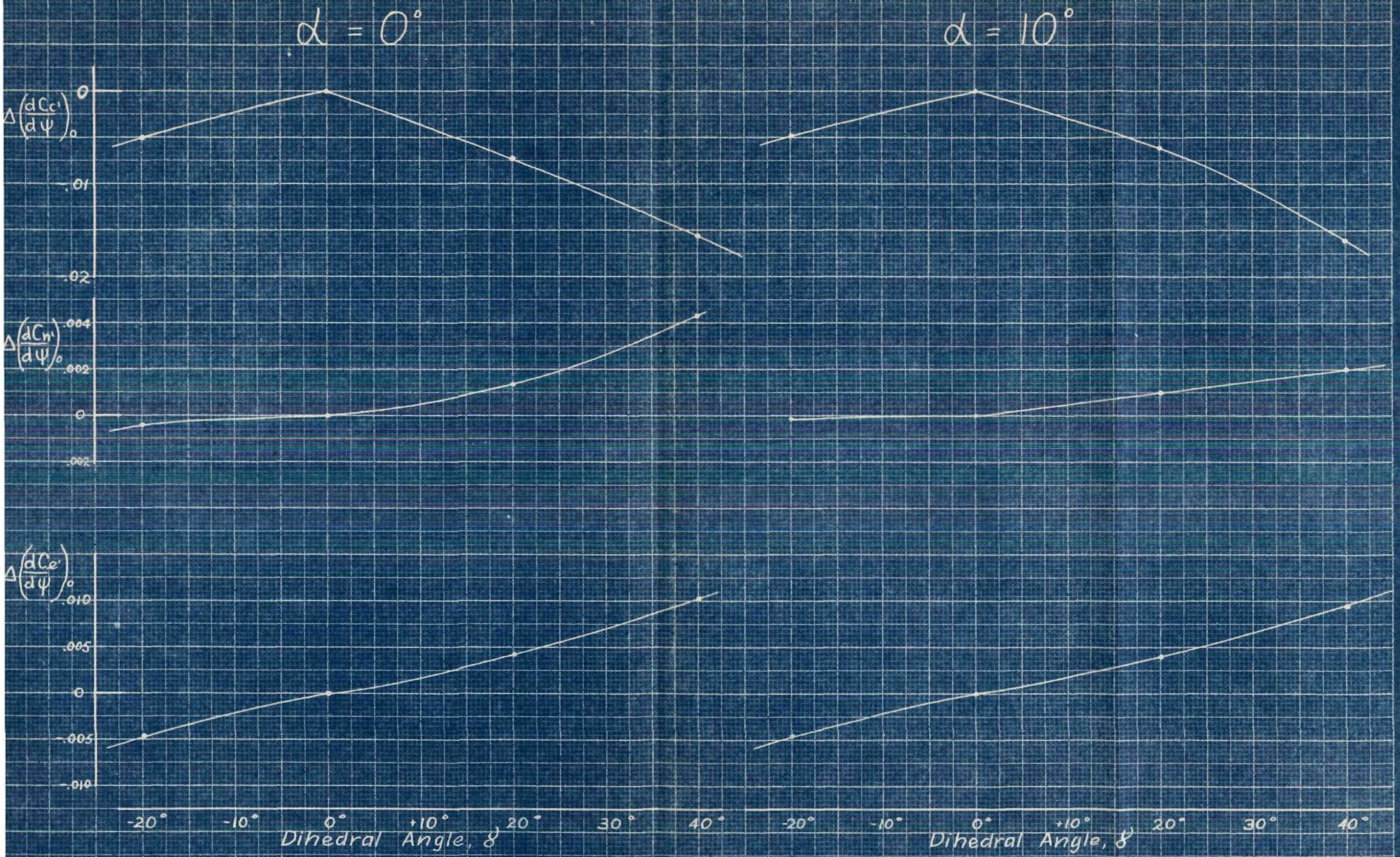


FIG. 31 EFFECT OF DIHEDRAL ON RATES OF CHANGE OF ROLLING-MOMENT, YAWING-MOMENT, AND CROSS-WIND FORCE COEFFICIENTS WITH ANGLE OF YAW